UNIT – I

Introduction to DC & AC Circuits

Ohm's Law, R, L, C Components, Kirchhoff's Laws, Types of Sources, Simple problems on Resistive Networks, Series Parallel Circuits, Star Delta and Delta Star Transformation. Sinusoidal waveforms and Basic Definitions, Root Mean Square and average values of sinusoidal Currents and Voltages. Form Factor and Peak Factor.

Network Theorems: Thevenin's, Norton's, Maximum Power Transfer and Superposition Theorems for DC Excitations.

Two Port Networks: Two Port Network Parameters – Impedance, Admittance, Transmission and Hybrid Parameters and Their Relations.

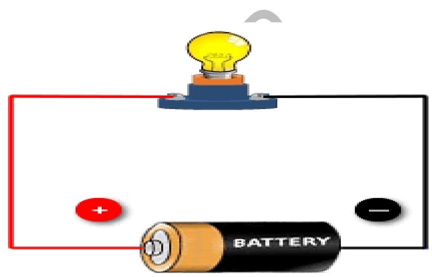
Circuit: An Electric circuit is an interconnection of various elements in which there is closed path for the flow of current.

Basic Components of a Circuit:

>Source: It is the part of the circuit which is capable of delivering energy to external devices connected to it. E.g. Battery, Generator, UPS etc.

>Load: it is the part of the circuit which is capable of absorbing the energy from the source and stores it or dissipates in the form of heat or light. E.g. Lamps, fans, heaters etc.

>Connecting wires: These are the part of the circuit which acts as medium to transfer the energy form source to load.



Network: Interconnection of two or more simple circuit elements is called as network. (the network may or may not contain closed path)

NETWORK ELEMENTS:

i) Active and Passive elements.
ii) Linear and Non-linear elements.
iii) Bi-lateral and Unilateral elements.
iv) Lumped and Distributed elements.

***<u>Active and Passive elements</u>*:**

Active elements: Active elements are the elements of a circuit which possess energy of their own and capable of delivering power to some external device. They are capable of delivering an average power greater than zero over an infinite period of time. E.g. Sources, Battery etc.

Active network or circuit: a circuit or network consisting of at least one active element is called active network.

Passive elements: these elements are capable only of receiving power. They cannot supply average power greater than zero over an infinite period of time. Some elements are capable of storing finite amount of energy and deliver it later to external elements. E.g. Resistors, Inductors, Capacitors.

Passive network or circuit: the network that consists of all passive elements is called passive network.

Linear and Non-linear elements:

Linear elements: Linear elements show the linear characteristics of voltage & current. That is its voltage-current characteristics are at all-times a straight-line through the origin.

For example, the current passing through a resistor is proportional to the voltage applied through its and the relation is expressed as V α I or V = IR (Elements which obeys ohms law). A linear element or network is one which satisfies the principle of superposition, i.e., the principle of homogeneity and additive.

E.g. Resistors, inductors and capacitors.

Non-linear elements: The element's in which V-I characteristics do not follow the linear pattern i.e. the current passing through it does not change linearly with the linear change in the voltage across it are called nonlinear elements.(Elements which does not obey ohms law).

E.g. All the semiconductor devices such as diode, transistor.

Bilateral & Unilateral elements:

Bilateral elements: An element is said to be bilateral, when the same relation exists between voltage and current for the current flowing in either directions. **Eg**: Voltage source, Current source, resistance, inductance & capacitance. The circuits containing them are called bilateral circuits.

Unilateral elements: An element is said to be unilateral, when the same relation does not exist between voltage and current when current flowing in both directions. The circuits containing them are called unilateral circuits. **Eg**: Vacuum diodes, Silicon Diodes, Selenium Rectifiers etc.

The circuits containing them are called unilateral circuits.

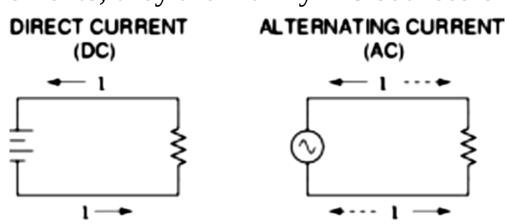
Lumped and Distributed Elements:

Lumped elements: Lumped elements are those elements which are very small in size & which are physically and electrically separable. **E.g**. capacitors, resistors, inductors.

Distributed elements: are those which are not electrically & physically separable for analytical purposes. For example a transmission line has distributed parameters(R, L&C) along its length and may extend for hundreds of miles.

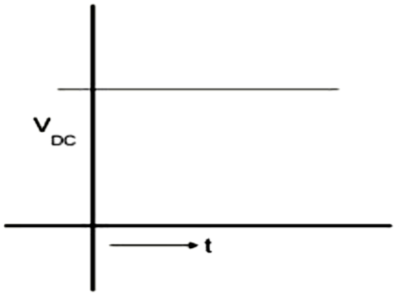
ELECTRICAL SOURCES

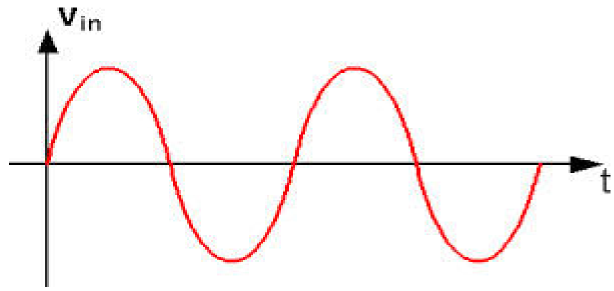
Electrical sources are the active elements; they are mainly DC sources & AC sources.



DC sources: The sources whose magnitude does not change with change in time. They have constant value w.r.t time with constant polarity. E.g. Battery, RPS, DC generators.

AC sources: the sources whose magnitude change with change in time. Their magnitude varies as sinusoidal w.r.t time. E.g. Power from supply mains, alternator, Inverters.





These AC and DC sources are classified into: a) Voltage sources b) Current sources

Voltage sources: A Voltage source has a specified voltage across its terminals, independent of current flowing through it.

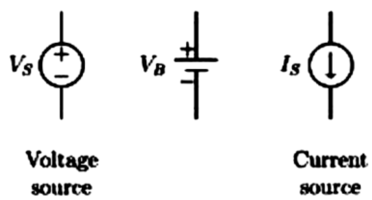
Current sources: A current source has a specified current through it independent of the voltage appearing across it.

These voltage and current sources are categorized into

a) Independent sources b) Dependent sources.

Independent sources:

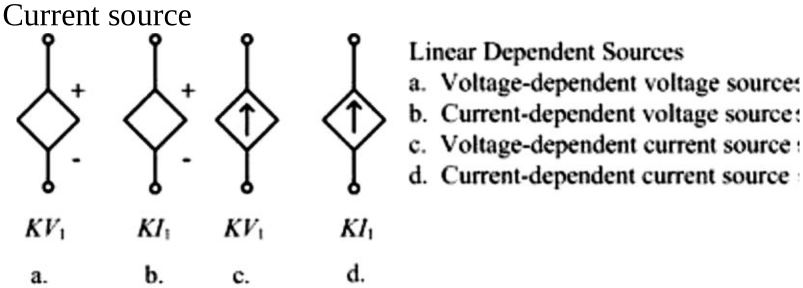
- Independent voltage source: the voltage of the voltage source is completely independent of source current they represented as shown.
- Independent current source: the current of the current source is completely independent of the voltage, then the sources is called as independent current source.



Dependent sources: The sources in which the source voltage or current depends on some other quantity in the circuit which may be either a voltage or a current anywhere in the circuit are called 'Dependent sources' or 'Controlled sources'.

There are four possible dependent sources.

a) Voltage dependent Voltage source
b) Current dependent Voltage source
c) Voltage dependent Current source
d) Current dependent Current source

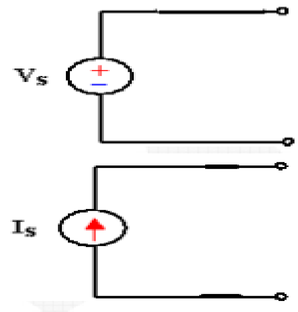


The independent sources may be ideal sources or practical sources. But ideal sources are practically not possible to develop.

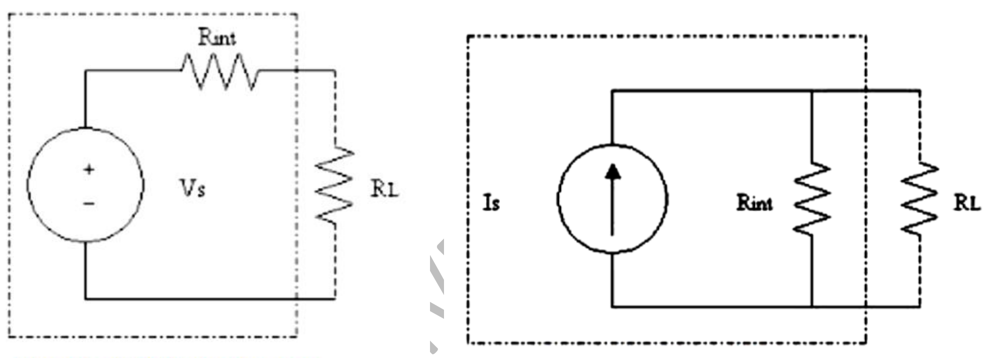
IDEAL SOURCES:

Ideal voltage source: An ideal voltage source is one which delivers energy to the load at a constant terminal voltage, irrespective of the current drawn by the load.

Ideal current source: An ideal current source is one which delivers energy with a constant current to the load, irrespective of the terminal voltage.
As the value of the internal resistance of a practical voltage source is very small, its terminal voltage is assumed to be almost constant.



PRACTICAL SOURCE:



Practical Voltage Source　　Practical Current Source

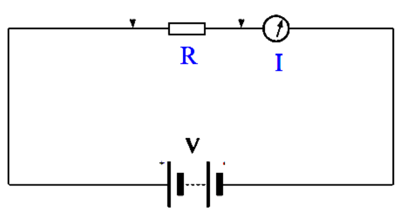
Ohm's Law states that at constant temperature, the current flowing through cross section of a conductor in a circuit is directly proportional to the applied potential difference across the ends of a conductor.

$I \propto V$ or $I=V/R$ where R is the resistance of the conductor.

Ohm's law can be expressed in a mathematical form: $V=IR$

Where:

V = voltage expressed in Volts
I = current expressed in Amps
R = resistance expressed in Ohms



Ohm’s Law relates Current (I), Voltage (E) and Resistance (R).

$$\boxed{I = \frac{V}{R} \text{ or } V = IR \text{ or } R = \frac{V}{I}}$$

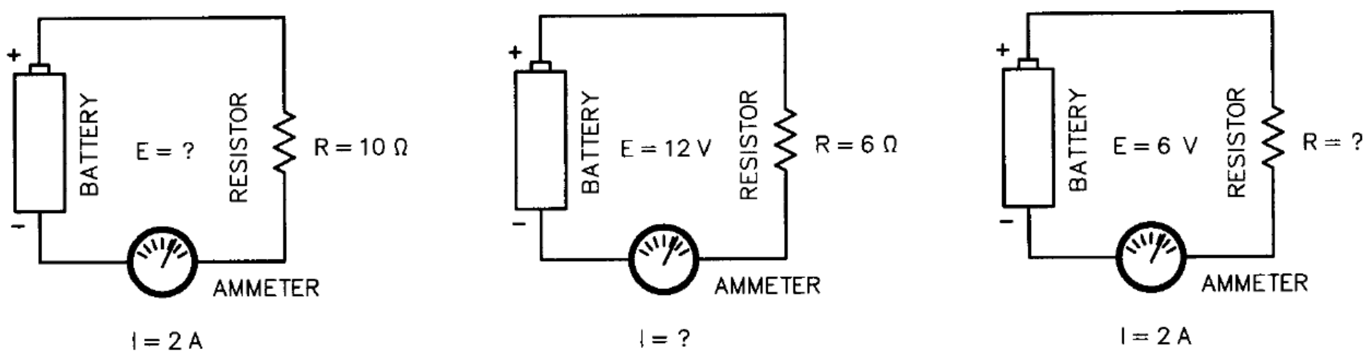
Ohm's law can be applied for both A.C. and D.C circuits provided the circuit must contain only linear elements. In case of A.C circuits, resistance is replaced by impedance.

Resistance of a Conductor Depends on

1. Length of the conductor.
2. Cross sectional area of the conductor.
3. Resisitivity of the material.
4. Temperature of the conductor.

$\therefore$ Resistance of the conductor $R = \frac{l}{a}\rho$

Where ρ is the resistivity of the material and the units are ohm-meters.



GIVEN: I = 2 AMPERES
R = 10 OHMS

FIND: E (VOLTAGE)

E = I × R = 2 × 10 = 20

VOLTAGE EQUALS 20 VOLTS

GIVEN: E = 12 VOLTS
R = 6 OHMS

FIND: I (CURRENT)

$I = \frac{E}{R} = \frac{12}{6} = 2$

CURRENT EQUALS TWO AMPERES

GIVEN: E = 6 VOLTS
I = 2 AMPERES

FIND: R (RESISITANCE)

$R = \frac{E}{I} = \frac{6}{2} = 3$

RESISTANCE EQUALS THREE OHMS

Example:. The current flowing through a resistor is 0.8 A when a p.d. of 20 V is applied. Determine the value of the resistance.

Solution:

$$\text{From Ohm's law, resistance } R = \frac{V}{I} = \frac{20}{0.8} = \frac{200}{8} = \mathbf{25\ \Omega}$$

Kirchhoff`s Laws:

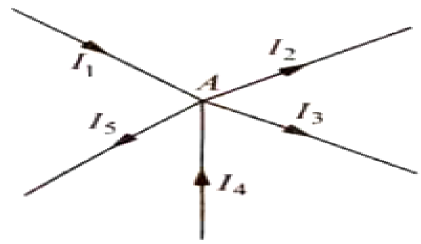
Kirchhoff's laws are used for solving electrical networks which may not be readily solved by using ohms law. Kirchhoff`s laws, two in number, are particularly useful in determining the equivalent resistance of a complicated network of conductors and for calculating the currents flowing in the various conductors.

Kirchhoff`s Point Law or Current Law (KCL)

In any electrical network, the algebraic sum of the currents meeting at a point (or junction) is Zero.

That is the total current ***entering*** a junction is equal to the total current ***leaving*** that junction.

Consider the case of a network shown in Fig (a).



$I_1+(-I_2)+(-I_3)+(+I_4)+(-I_5) = 0$

$I_1+I_4-I_2-I_3-I_5 = 0$

Or

$I_1+I_4 = I_2+I_3+I_5$

Or

Incoming currents =Outgoing currents

Kirchhoff's Mesh Law or Voltage Law (KVL)

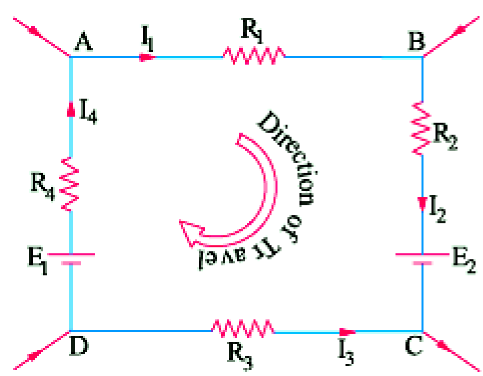
The algebraic sum of the voltage rises (voltage drops) around a closed path in a specified direction of a network is zero.

In any electrical network, the algebraic sum of the products of currents and resistances in each of the element in any closed path (or mesh) in a network plus the algebraic sum of the e.m.f.'s in that path is zero. That is, $\sum IR + \sum e.m.f = 0$ round a mesh

In applying Kirchhoff's laws to specific problems, particular attention should be paid to the algebraic signs of voltage drops and e.m.f's. If voltage drop is taken as positive, the voltage rise is to be taken as negative and vice versa.

Consider the closed path *ABCDA* in Fig .

As we travel around the mesh in the clockwise direction, different voltage drops will have the following signs :



I_1R_1 is - ve (fall in potential)

I_2R_2 is - ve (fall in potential)

I_3R_3 is + ve (rise in potential)

I_4R_4 is - ve (fall in potential)

E_2 is - ve (fall in potential)

E_1 is + ve (rise in potential)

Using Kirchhoff's voltage law, we get

$$-I_1R_1 - I_2R_2 - I_3R_3 - I_4R_4 - E_2 + E_1 = 0$$

(Or) $$I_1R_1 + I_2R_2 - I_3R_3 + I_4R_4 = E_1 - E_2$$

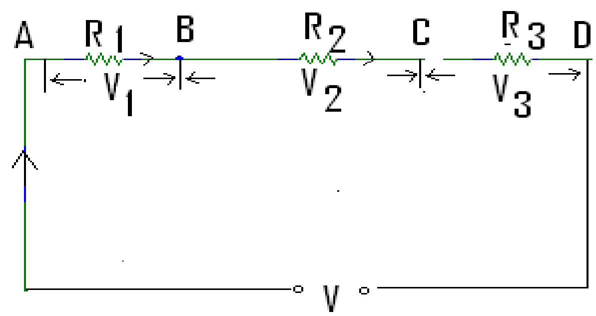
Assumed Direction of Current:

In applying Kirchhoff's laws to electrical networks, the direction of current flow may be assumed either clockwise or anticlockwise. If the assumed direction of current is not the actual direction, then on solving the question, the current will be found to have a minus sign.

If the answer is positive, then assumed direction is the same as actual direction. However, the important point is that once a particular direction has been assumed, the same should be used throughout the solution of the question.

Kirchhoff's laws are applicable both to d.c. and a.c. voltages and currents. However, in the case of alternating currents and voltages, any e.m.f. of self-inductance or that existing across a capacitor should be also taken into account.

Resistance in series: If three conductors having resistances R_1, R_2 and R_3 are joined end on end as shown in fig below, then they are said to be connected in series. It can be proved that the equivalent resistance between points A & D is equal to the sum of the three individual resistances.



For a series circuit, the current is same through all the three conductors but voltage drop across each is different due to its different values of resistances and is given by ohm`s Law and the sum of the three voltage drops is equal to the voltage supplied across the three conductors.

$\therefore$ $V= V_1+V_2+V_3 = IR_1+IR_2+IR_3$

But $V= IR$

where R is the equivalent resistance of the series combination.

$IR = IR_1+IR_2+IR_3$

Or $R = R_1 + R_2 + R_3$

<u>The main characteristics of a series circuit are</u>

1. Same current flows through all parts of the circuit.
2. Different resistors have their own voltage drops.
3. Voltage drops are additive.

4. Applied voltage equals the sum of different voltage drops.
5. Resistances are additive.
6. Powers are additive

Voltage Divider Rule

In a series circuit, same current flows through each of the given resistors and the voltage drop varies directly with its resistance.

> Consider a circuit in which, a 24- V battery is connected across a series combination of three resistors of 4Ω each. Determine the voltage drops across each resistor?

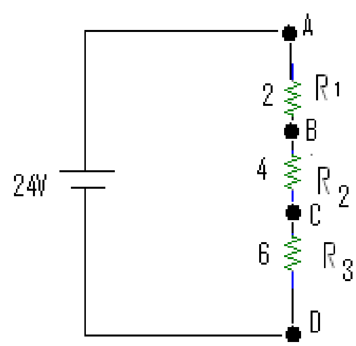
Total resistance $R = R_1 + R_2 + R_3 = 12\ \Omega$

According to Voltage Divider Rule, voltages divide in the ratio of their resistances and hence the various voltage drops are

$$V_1 = V\frac{R_1}{R} = 24\ X\ \frac{2}{12} = 4V$$

$$V_2 = V\frac{R_2}{R} = 24\ X\ \frac{4}{12} = 8V$$

$$V_3 = V\frac{R_3}{R} = 24\ X\ \frac{6}{12} = 12V$$



Resistances in Parallel:

Three resistances, as joined in Fig.below are said to be connected in parallel. In this case

(I) Potential difference across all resistances is the same

(ii) Current in each resistor is different and is given by Ohm's Law

(iii) The total current is the sum of the three separate currents.

$$I = I_1 + I_2 + I_3 = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

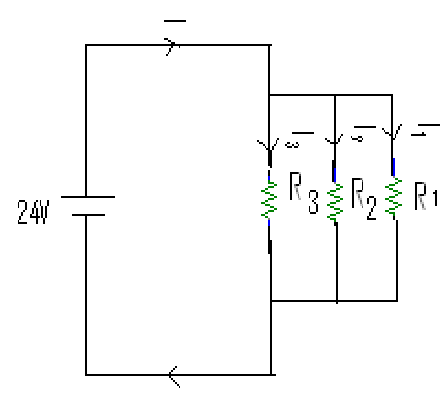
$I = \frac{V}{R}$ where V is the applied voltage.

R = equivalent resistance of the parallel combination.

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$G = G_1 + G_2 + G_3$



The main characteristics of a parallel circuit are:

1. Same voltage acts across all parts of the circuit
2. Different resistors have their individual current.

3. Branch currents are additive.

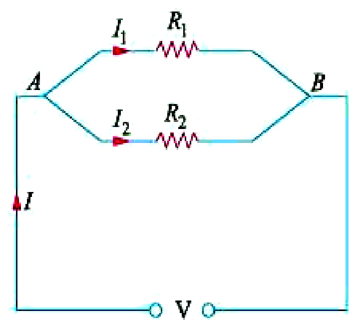
4. Conductances are additive.

5. Powers are additive

Division of Current in Parallel Circuits

Two resistances are joined in parallel across a voltage *V*. The current in each branch, given by Ohm's law, is

$I_1 = \frac{VI}{R_1}$ and $I_2 = \frac{V}{R2}$



$\frac{I_1}{I_2} = \frac{R_1}{R_2}$

As $\frac{I}{R_1} = G_1 \; and \; \frac{I}{R_2} = G_2$

$\frac{I_1}{I_2} = \frac{G_1}{G_2}$

Hence, the division of current in the branches of a parallel circuit is directly proportional to the conductance of the branches or inversely proportional to their resistances.

The branch currents are also expressed in terms of the total circuit current

$Now \qquad I_1 + I_2 = I; \;\therefore\; I_2 = I - I_1 \quad \therefore \frac{I_1}{I-I_1} = \frac{R_2}{R_{12}}$ or $I_1R_1 = R_2(I - I_1)$

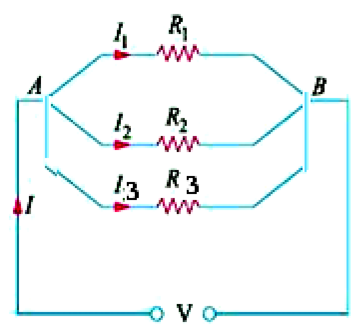
$I_1 = I\frac{R_1}{R_1-R_2} = I\frac{G_1}{G_1+G_2}$ and $I_2 = I\frac{R_1}{R_1-R_2} = I\frac{G_1}{G_1+G_2}$

Take the case of <u>three resistors in parallel connected across a voltage 'V'</u>

Total current is $I=I_1+I_2+I_3$

Let the equivalent resistance be *R*. Then

$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$



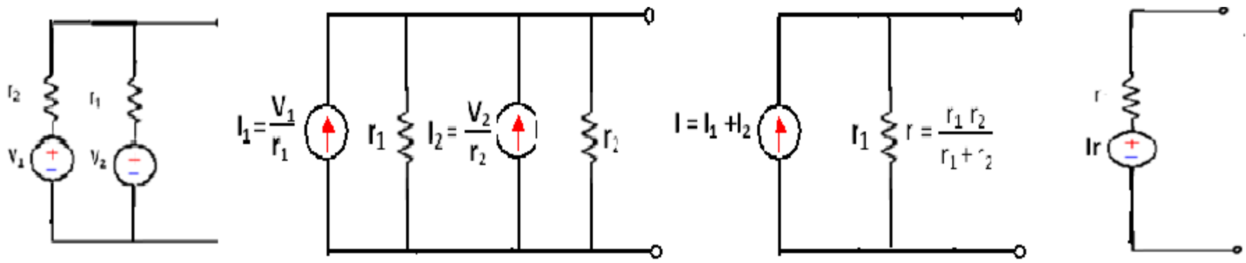
R = $\frac{R_1R_2R_3}{R_1R_3+R_2R_3+R_1R_2}$

I₁ = $I\left[\frac{R_2R_3}{R_1R_3+R_2R_3+R_1R_2}\right] = I.\frac{G_1}{G_1+G_2+G_3}$

I₂= $I\left[\frac{R_1R_3}{R_1R_3+R_2R_3+R_1R_2}\right] = I.\frac{G_2}{G_1+G_2+G_3}$

I₃ = $I\left[\frac{R_1R_2}{R_1R_3+R_2R_3+R_1R_2}\right] = I.\frac{G_3}{G_1+G_2+G_3}$

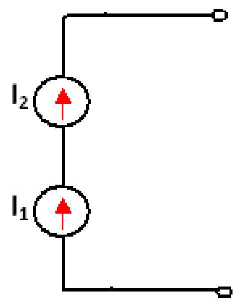
Practical voltage sources connected in parallel



Equivalent Circuit

Single Equivalent Voltage Source

Ideal current sources connected in series

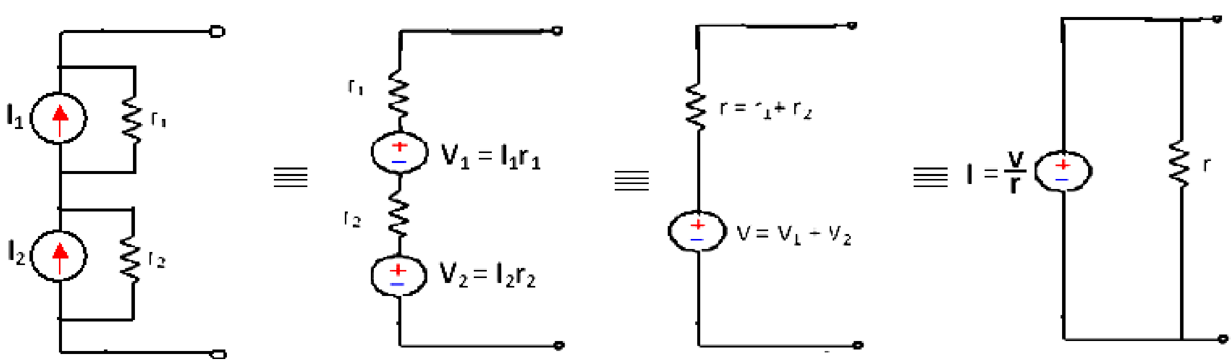


When ideal current sources are connected in series, what current flows through the line is ambiguous. Hence such a connection is not permissible.

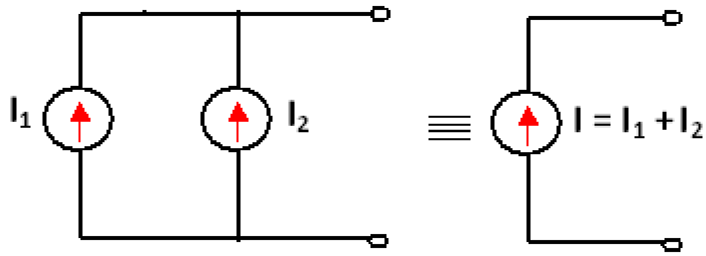
However, it $I_1 = I_2 = I$, then the current in the line is I.

But, such a connection is not necessary as only one current source serves the purpose.

Practical current sources connected in series:

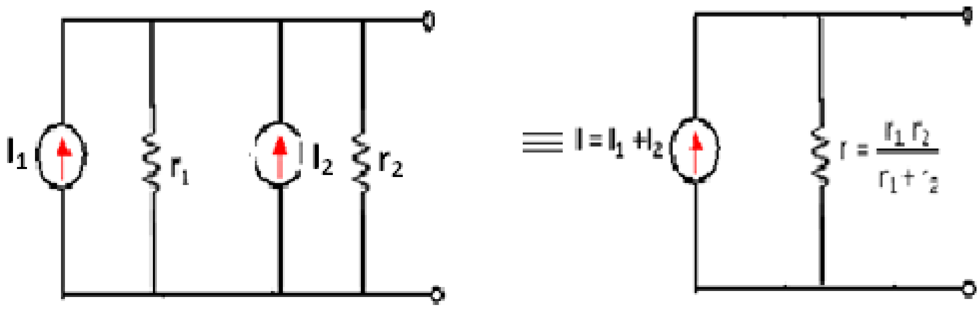


Ideal current sources connected in parallel



Two ideal current sources in parallel can be replaced by a single equivalent ideal current source.

Practical current sources connected in parallel



Source transformation:

This is used to convert the given voltage source in series with resistance into current source in parallel with same resistance and vice versa. This technique is useful in reducing the complexity of the given circuit.

A current source or a voltage source drives current through its load resistance and the magnitude of the current depends on the value of the load resistance.

Consider a practical voltage source and a practical current source connected to the same load resistance R_L as shown in the figure

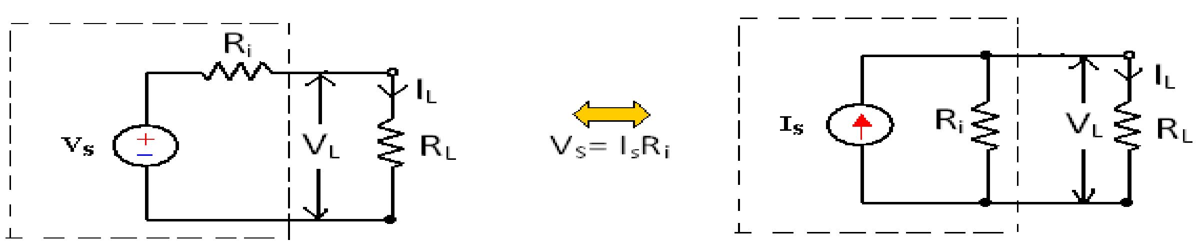


Fig.(a) Fig.(b)

R_i in the figure shown represents the internal resistance of the voltage source V_S and current source I_S.

Two sources are said to be identical, when they produce identical terminal voltage V_L and load current I_L.

The circuits in figure represents a practical voltage source & a practical current source respectively, with load connected to both the sources.

The terminal voltage V_L and load current I_L across their terminals are same.

Hence the practical voltage source & practical current source shown in the dotted box of figure are equal.

The two equivalent sources should also provide the same open circuit voltage & short circuit current.

From fig (a)

$$I_L = \frac{Vs}{R+R_L}$$

From fig (b)

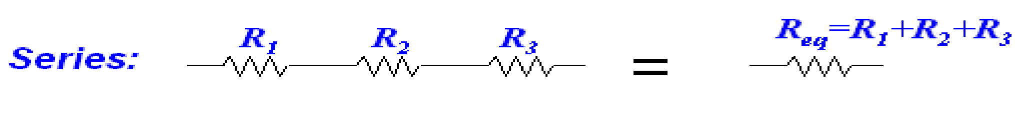
$$I_L = I \frac{R}{R+R_L}$$

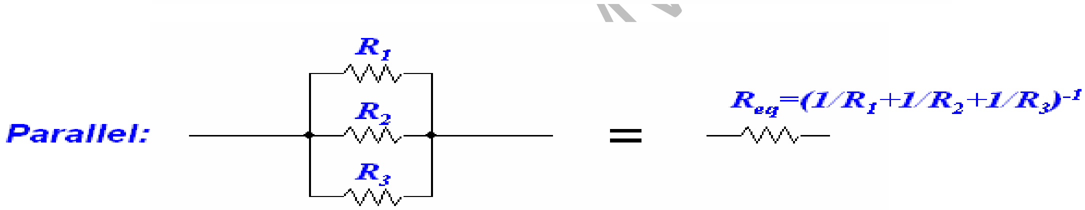
$$\therefore \frac{Vs}{R+R_L} = I \frac{R}{R+R_L}$$

$$V_S = IR \quad \text{or} \quad I = \frac{Vs}{R}$$

Hence a voltage source V_s in series with its internal resistance R can be converted into a current source $I = \frac{Vs}{R}$, with its internal resistance R connected in parallel with it. Similarly a current source I in parallel with its internal resistance R can be converted into a voltage source V = IR in series with its internal resistance R.

Resistance in series & parallel:



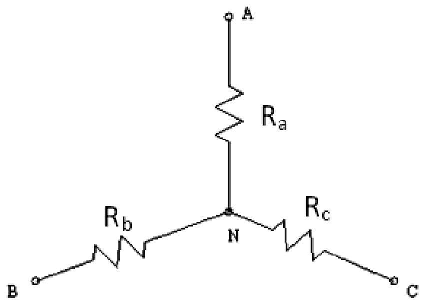


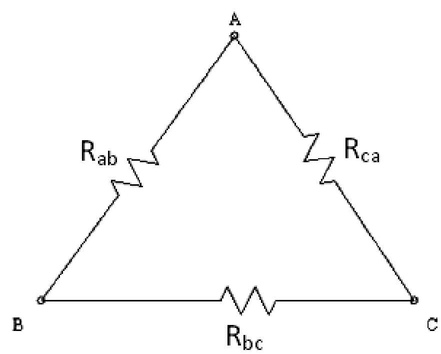
Circuit elements	**Voltage(V)**	**Current(A)**	**Power(W)**
Resistor R (Ohms Ω)	V=RI	$I=\frac{V}{R}$	$P = i^2R$
Inductor L (Henry H)	$V=L\frac{di}{dt}$	$I = \frac{1}{L}\int vdt + i_o$	$P = Li\,\frac{di}{dt}$
Capacitor C (Farad F)	$I=\frac{1}{C}\int idt + v_0$ where v_0 is the initial voltage across capacitor	$I = C\,\frac{dv}{dt}$	$P = CV\,\frac{dv}{dt}$

Star - Delta (Y- Δ) transformation

The methods of series, parallel and series – parallel combination of elements do not always lead to simplification of networks. Such networks are handled by Star Delta transformation.

Figure a shows three resistances R_a, R_b, R_c connected in star to three nodes A, B, C and a common point N & figure b shows three resistances connected in delta between the same three nodes A,B,C. If these two networks are to be equivalent then the resistance between any pair of nodes of the delta connected network of a) must be the same as that between the same pair of nodes of the star – connected network of fig b).





Star resistances in terms of delta

Equating resistance between node pair AB

$$R_a + R_b = R_{ab} \ // \ (R_{bc} + R_{ca}) = \frac{R_{ab}\,R_{bc} + R_{ab}\,R_{ca}}{R_{ab}+R_{bc}+R_{ca}} \quad \text{\_ (1)}$$

Similarly for node pair BC

$$R_b + R_c = R_{bc} \ // \ (R_{ca} + R_{ab}) = \frac{R_{bc}\,R_{ca} + R_{bc}\,R_{ab}}{R_{ab}+R_{bc}+R_{ca}} \quad \text{\_ (2)}$$

For Node pair CA

$$R_c + R_a = R_{ca} \ // \ (R_{ab} + R_{bc}) = \frac{R_{ca}\,R_{ab} + R_{ca}\,R_{bc}}{R_{ab}+R_{bc}+R_{ca}} \quad \text{\_ (3)}$$

Subtracting (2) from (3) gives

$$R_a - R_b = \frac{R_{ca}\,R_{ab} + R_{bc}\,R_{ab}}{R_{ab}+R_{bc}+R_{ca}} \quad \text{\_ (4)}$$

Adding (1) and (4) gives

$$R_a = \frac{R_{ab}R_{ca}}{R_{ab}+R_{bc}+R_{ca}} \quad \text{\_ (5)}$$

Similarly

$R_b = \frac{R_{bc}\,R_{ab}}{R_{ab}+R_{bc}+R_{ca}}$ _ (6)

$R_c = \frac{R_{ca}R_{bc}}{R_{ab}+R_{bc}+R_{ca}}$ _ (7)

Thus the equivalent star resistance connected to a node is equal to the product of the two delta resistances connected to the same node decided by the sum of delta resistances.

Delta resistances in terms of star resistances:

Dividing (5) by (6) gives

$$\frac{R_a}{R_b} = \frac{R_{ca}}{R_{bc}} \qquad \therefore R_{ca} = \frac{R_a R_{bc}}{R_b}$$

Dividing (5) by (6) gives

$$\frac{R_a}{R_c} = \frac{R_{ab}}{R_{bc}} \qquad \therefore R_{ab} = \frac{R_a R_{bc}}{R_c}$$

Substituting for R_{ab} & R_{ca} in equation (5) simplifying gives

$$R_a = \frac{\frac{R_a R_{bc}}{R_c}\,\frac{R_a R_{bc}}{R_b}}{\frac{R_a R_{bc}}{R_c} + \frac{R_a R_{bc}}{R_b} + R_{bc}}$$

$$R_a = \frac{R_a\left(\frac{R_{bc}^{\,2}}{R_b R_c}\right)}{R_a\left(\frac{R_{bc}}{R_c}+\frac{R_{bc}}{R_b}+\frac{R_{bc}}{R_a}\right)}$$

$$R_a\left(\frac{R_{bc}}{R_c}+\frac{R_{bc}}{R_b}+\frac{R_{bc}}{R_a}\right) = R_a\left(\frac{R_{bc}^{\,2}}{R_b R_c}\right)$$

$$\frac{R_{bc}(R_b R_c + R_a R_c + R_a R_b)}{R_a R_b R_c} = \frac{R_{bc}^{\,2}}{R_a R_b R_c}$$

$$R_{bc} = \frac{(R_b R_c + R_a R_c + R_a R_b)}{R_a}$$

$$= R_b + R_c + \frac{R_c R_a}{R_b}$$

Similarly

$$R_{ca} = R_c + R_a + \frac{R_c R_a}{R_b}$$

$$R_{ab} = R_a + R_b + \frac{R_a R_b}{R_c}$$

Thus the equivalent Delta resistance between two nodes is the sum of two star resistances connected to those nodes plus the product of the same two star resistances divided by the third star resistance.

$R_1 = \frac{R_A R_B}{R_A + R_B + R_C}$ $\qquad$ $R_A = R_1 + R_2 + \frac{R_1 R_2}{R_3}$

$R_2 = \frac{R_A R_C}{R_A + R_B + R_C}$ $\qquad$ $R_B = R_1 + R_3 + \frac{R_1 R_3}{R_2}$

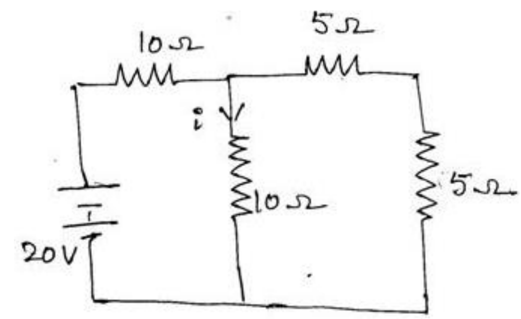
$R_1 = \frac{R_B R_C}{R_A + R_B + R_C}$ $\qquad$ $R_C = R_2 + R_3 + \frac{R_2 R_3}{R_1}$

If all are similar equal to R

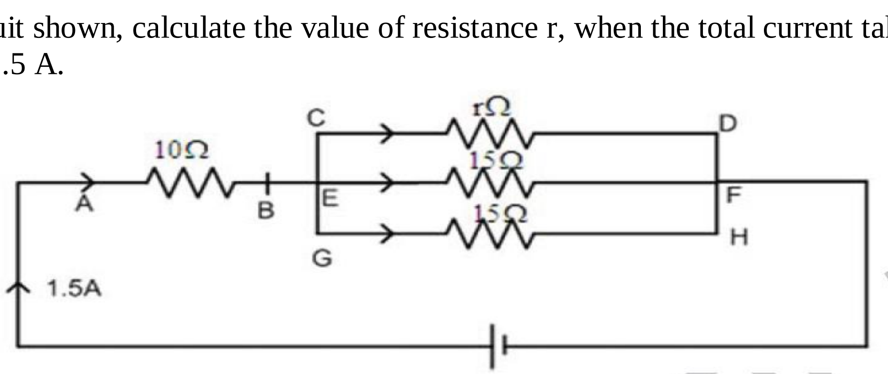
$R_1 = \frac{R^2}{3R} = \frac{R}{3}$ $\qquad$ $R_A = 3R$

Practice problems on Ohms law, KVL,KCL

1. Define and explain resistance, inductance, and capacitance.
2. Two resistances of 1.5 Ω and 3.5 Ω are connected in parallel and this parallel combination is connected in series with a resistance of 1.95Ω . Find the equivalent resistance of the circuit. What current will it draw if connected to a 30V supply.
3. State and explain ohm's law
4. Three resistances 2Ω , 4Ω and 6Ω are connected in series across a voltage supply, voltage across 2 Ω resistor is 4V. Find the voltage across remaining resistances and total voltage.
5. Find the current in the following figure.
6. Define and explain basic circuit components.
7. Define and explain Kirchhoff's law.
8. Three resistors of 5 Ω, 10 Ω, 15 Ω are joined in parallel. If the current in 10 Ω resistor is 3A, what is the current in other resistors and the total current?



9. For the circuit shown, calculate the value of resistance r, when the total current taken by the network is 1.5 A.



10. Derive the equation for equivalent resistance when connected in (i) series (ii) parallel.

11. Three resistors R1,R2 & R3 are connected in series with a constant voltage source of 'V' volts. The voltage across R1 is 4V, power loss in R2 is 16W and the value of R3 is 6 ohms. If the current flowing through the circuit is 2A, find the voltage 'V'.
12. A current of 10 A flows through a resistor for 10 min. and the power dissipated by the resistor is 100 W. Find the p.d. Across the resistor and the energy supplied to the circuit.
13. Four resistors of 2 ohm, 3 ohm, 4 ohm & 5 ohm respectively, are connected in parallel. What potential difference must be applied to the group in order that total power of 100 W may be absorbed?
14. Derive an expression for the effective resistance of three resistors connected in parallel
15. Derive an expression of energy stored in a capacitance from the fundamentals.
16. Explain the passive elements in detail
17. Three resistors of 5 ohm, 10 ohm and 15 ohm are joined in parallel. If the current in 10 ohm resistor is 3 A, what is the current in other resistors and the total current?
18. Consider a 230 V, 100 W incandescent lamp. Determine (i) the lamp resistance (ii) the lamp current and (iii) the energy consumed in 8 hours.

UNIT – II

SYLLABUS

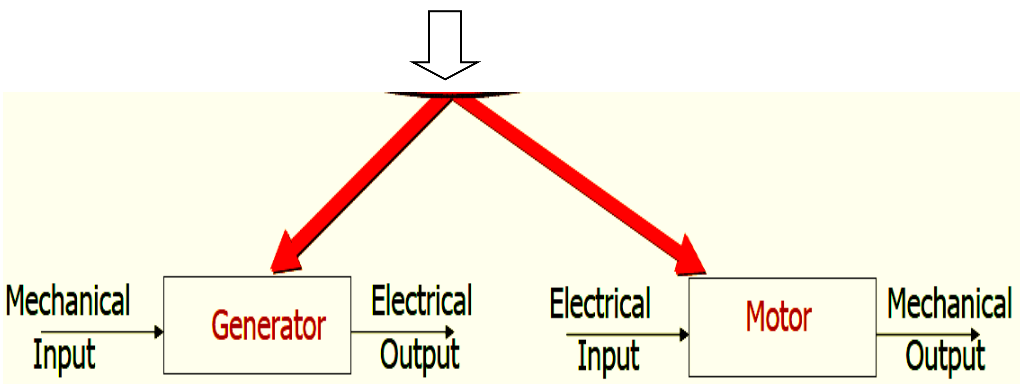
D.C. Generators: Constructional details of D.C. machines, Principle of Operation of D.C. generators, Types of D.C Generators, E.M.F Equation, O.C.C. of a D.C. Shunt Generator

D.C. Motors: Principle of Operation of DC Motors, Torque Equation, Losses and Efficiency Calculation, Speed Control of D.C. shunt motor (Armature voltage control and Field flux control). Swinburne's Test and Applications.

Introduction

1. An electromechanical energy conversion device is one which converts electrical energy into mechanical energy or vice versa is called a rotating machine. These are classified as AC & DC machines. E.g. Induction, synchronous and DC machines.
2. A D.C. machine can operate as either a motor or generator. DC machine mainly used as DC motors and the DC generators are rarely used. DC motors provides a fine control of the speed which cannot be attained by AC motors. Large DC motors are used in machine tools, printing presses, fans, pumps, cranes, paper mill, traction, textile mills and so on.

D.C. Machines



D.C. Generators

An electrical generator is a device that converts mechanical energy to electrical energy, generally using electromagnetic induction. The energy conversion in generator is based on the principle of the production of dynamically induced e.m.f.

Whenever a conductor cuts magnetic flux, dynamically induced e.m.f is produced in it according to Faraday's Laws of Electromagnetic induction. This e.m.f causes a current to flow if the conductor circuit is closed. Hence, two **basic essential parts** of an electrical generator are **(i) a magnetic field and (ii) a conductor or conductors which can so move as to cut the flux.**

The direction of induced e.m.f. (and hence current) is given by **Fleming's right hand rule**.

Working principle of Simple loop DC generator:

A simple machine (single loop generator) consists of a coil ABCD moving about it's own axis with a constant speed in a uniform magnetic field provided by permanent magnets or electromagnets. The ends of the coil are connected to two slip rings 'a' and 'b' fixed on a shaft. The brushes b1 & b2 (made of carbon or graphite) are used to collect current induced in the coil. The rotating coil may be called 'armature' and magnets are called' field magnets'.

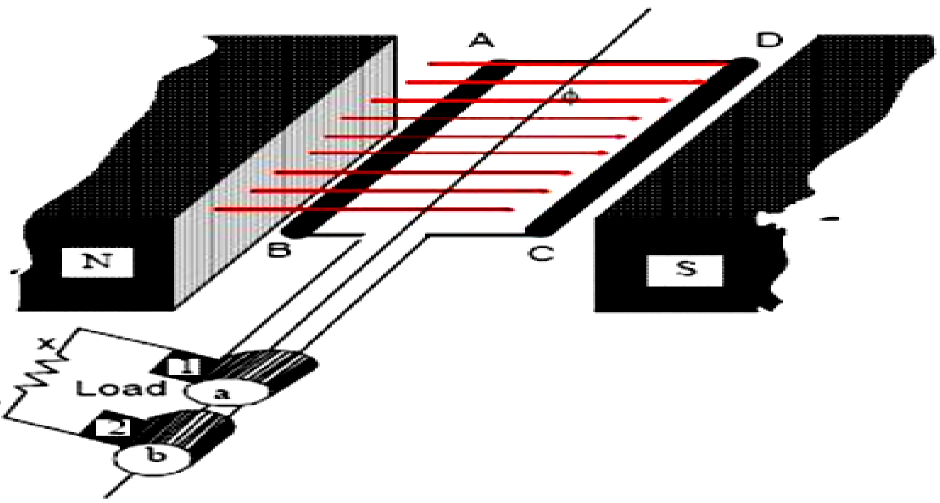
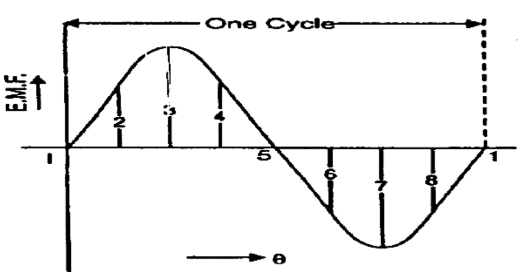
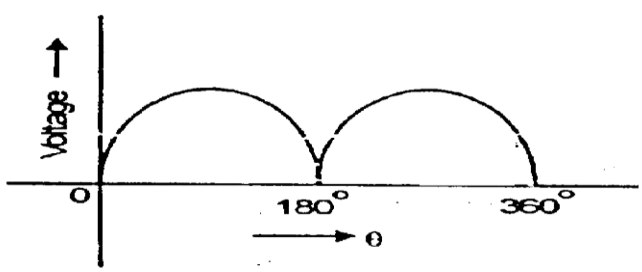


Fig. Simple loop generator.





As the loop rotates, the flux linking the coil sides AB and CD changes continuously. Hence the e.m.f induced in these coil sides also changes.

- *When the loop is in position no. 1, the generated e.m.f. is zero because the coil sides (AB and CD) are cutting no flux but are moving parallel to it.*
- *When the loop is in position no. 2, the coil sides are moving at an angle to the flux and, therefore, a low e.m.f. is generated as indicated by point2*
- *When the loop is in position no. 3, the coil sides (AB and CD) are at right angle to the flux and are, therefore, cutting the flux at a maximum rate. Hence at this instant, the generated e.m.f. is maximum as indicated by point 3.*
- *At position 4, the generated e.m.f. is less because the coil sides are cutting the flux at an angle.*
- *At position 5, no magnetic lines are cut and hence induced e.m.f. is zero as indicated by point 5 .*
- *At position 6, the coil sides move under a pole of opposite polarity and hence the direction of generated e.m.f. is reversed.*

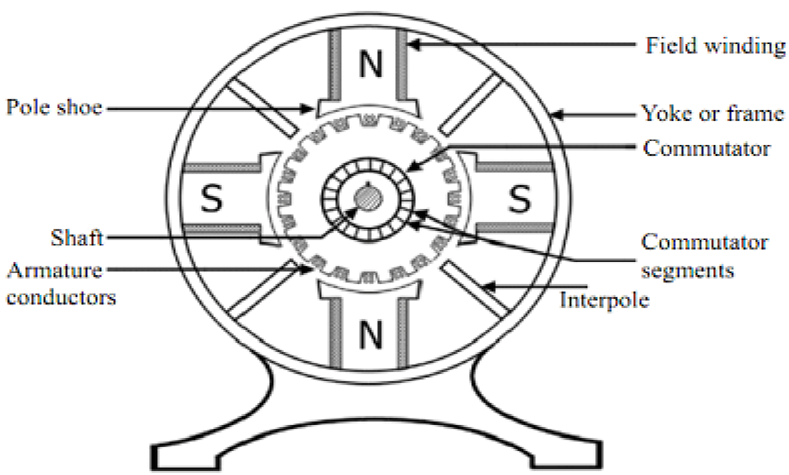
- *The maximum e.m.f in this direction (i.e., reverse direction, will be when the loop is at position 7 and zero when at position 1. This cycle repeats with each revolution of the coil.*

Note that e.m.f. generated in the loop is alternating one. The alternating voltage generated in the loop can be converted into direct voltage by a device called commutator. We then have the d.c. generator. In fact, a commutator is a mechanical rectifier.

Construction of d.c generator: A DC machine consists of two basic parts, stator and rotor.

The d.c. generators and d.c. motors have the same general construction.
Any d.c. generator can be run as a d.c. Motor and vice-versa.
All d.c. machines have five principal components viz.,

(i) Field system
(ii) Armature core
(iii) Armature winding
(iv) Commutator
(v) Brushes



Field system:
The function of the field system is to produce uniform magnetic field within which the armature rotates. It consists of a number of salient poles bolted to the inside of circular frame (generally called yoke). Yoke is usually made of solid cast steel whereas the pole pieces are composed of stacked laminations.
Yoke: Yoke is a outer frame. It serves two purposes.
(i) It provides mechanical support for the poles and acts as a protecting cover for the whole machine.
(ii) It carries the magnetic flux produced by the poles.
The field coils are connected in such a way that adjacent poles have opposite polarity. The m.m.f. developed by the field coils produces a magnetic flux that passes through the pole pieces, the air gap, the armature and the frame.

Armature core:

- The armature core is keyed to the machine shaft and rotates between the field poles. It consists of slotted soft-iron laminations that are stacked to form a cylindrical core.
- The laminations are individually coated with a thin insulating film so that they do not come in electrical contact with each other. The purpose of laminating the core is to reduce the eddy current loss.

Armature winding:

- The slots of the armature core hold insulated conductors that are connected in a suitable manner. (Either in lap A=P or in wave A=2 type connection).This is known as armature winding.
- This is the winding in which "working" e.m.f. is induced.

Commutator:

- Commutator: is a mechanical rectifier, which converts the alternating voltage generated in the armature winding into direct voltage across the brush. It is made of copper segments insulated from each other by mica and mounted on the shaft of the machine. The armature windings are connected to the commutator segments

Brushes:

- The function of brushes is to simply collect the current from commutator.
  Brushes are made of carbon or Graphite and rectangular in shape.

Bearings: It uses ball bearings or roller type bearings.

Applications of DC Generators:

- They are used for general lighting.
- They are used to charge battery because they can be made to give constant output voltage.
- They are used for giving the excitation to the alternators.
- They are also used for small power supply.
- They are used for supplying field excitation current in DC locomotives for regenerative breaking.
- For electro plating
- Used to supply dc welding machines.

Types of D.C. Generators:

The magnetic field in a d.c. generator is normally produced by electromagnets rather than permanent magnets. Generators are generally classified according to their methods of field excitation. On this basis, d.c. generators are divided into the following two classes:

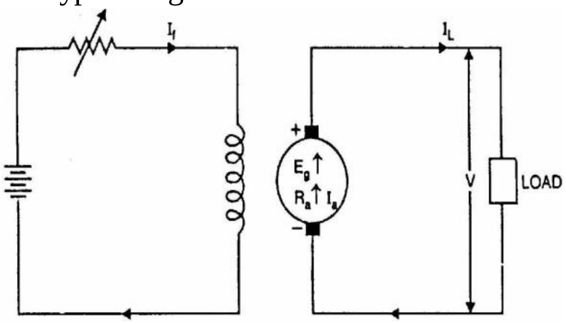
(i) Separately excited generator

(ii) Self excited generator

The behavior of a d.c. generator on load depends upon the method of field excitation adopted.

Separately Excited Generators:

A D.C. generator whose field magnet winding is supplied from an independent external D.C. source (e.g., a battery etc.) is called a separately excited generator. The voltage output depends upon the speed of rotation of armature and the field current (**Eg** = P φ Z N/ 60 A) . The greater the speed and field current greater is the generated e.m.f. It may be noted that separately excited D.C. generators are rarely used in practice. The D.C. generators are normally of self – excited type. Figure shows the connections of a separately excited generator.



Armature current, $\mathbf{I_a = I_L}$

Terminal voltage, $V = \mathbf{E_g - I_a R_a}$

Electric power developed = $\mathbf{E_g I_a}$

Power delivered to load $= \mathbf{E_g I_a - I_a^2 R_a = I_a (E_g - I_a R_a) = V I_a}$

Self Excited D.C. Generators

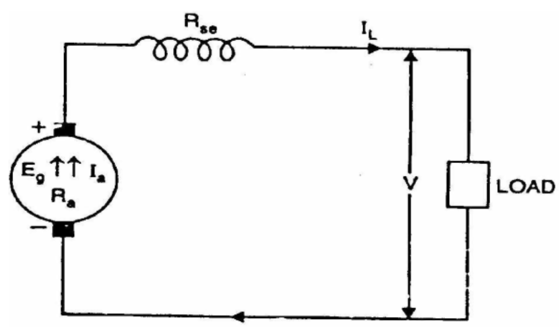
A d.c generator whose field magnet winding is supplied current from the output of the generator itself is called a self – excited generator.

There are three types of self-excited generators depending upon the manner in which the field winding is connected to the armature, namely

(i) Series generator (ii) shunt generator (iii) compound generator

(i) Series Generator:

In a series wound generator , the field winding is connected in series with armature winding so that whole armature current flows through the field winding as well as the load. Fig. shows the connections of series generator.



Armature current, $I_a = \mathbf{I_{se} = I_L = I}$ **(say)**

Terminal voltage, $\mathbf{V = E_g - I (R_a + R_{se})}$

Power developed in armature $= \mathbf{E_g I_a}$

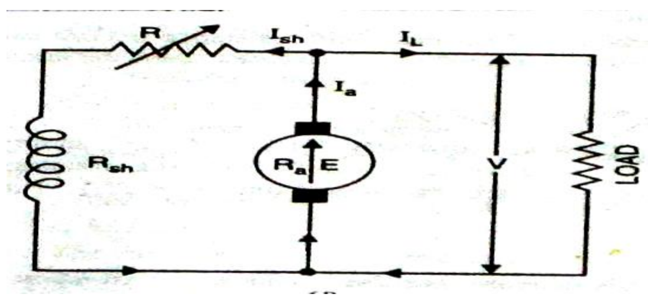
Power delivered to load $= \mathbf{E_g I_a - I_a^2 (R_a + R_{se})}$

$= \mathbf{I_a [E_g - I_a (R_a + R_{se})]}$

$= \mathbf{V I_a}$ **(or)** $\mathbf{V I_L}$

(ii) Shunt Generator:

In a shunt generator, the field winding is connected in parallel with the armature winding so that terminal voltage of the generator is applied across it



Shunt field current, **Ish** = **V/Rsh**

Armature current, **Ia** = $\mathbf{I_L}$ **+ Ish**

Terminal voltage, **V** = **Eg** – **Ia Ra**

Power developed in armature = **Eg Ia**

Power delivered to load = $\mathbf{V I_L}$

.

Figure : shunt wound generator.

(iii) Compound Generator:

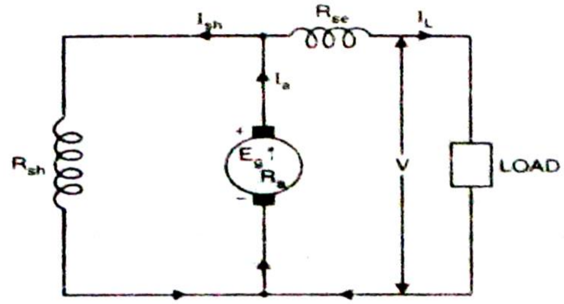
In a compound - wound generator there are two sets of field winding on each pole–one is in series and the other in parallel with the armature.

A compound generator may be:

a) **Short Shunt** in which only shunt field winding is in parallel with the armature winding.
b) **Long Shunt** in which shunt field winding is in parallel with both series field and armature winding.

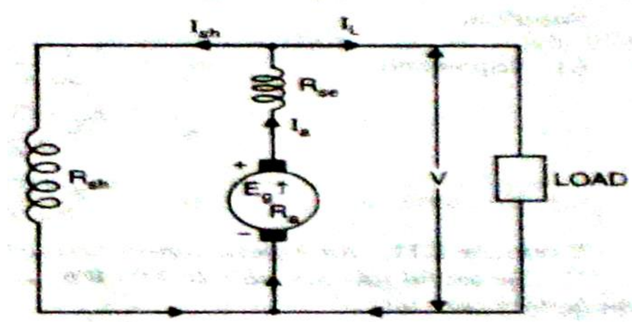
Short Shunt:

Series field current, $I_{se} = I_L$
Shunt field current, $I_{sh} = (V + I_{se} .R_{se})/ R_{sh}$
Terminal voltage, $V = E_g – I_a R_a – I_{se} R_{se}$
Power developed in the armature= $E_g I_a$
Power delivered to load = $V I_L$



Long Shunt:

Series field current, $\mathbf{I_{se} = I_a = I_L + I_{sh}}$
Shunt field current, $\mathbf{I_{sh} = V/R_{sh}}$
Terminal voltage, $\mathbf{V = E_g – I_a (R_a + R_{se})}$
Power delivered in the armature $\mathbf{= E_g I_a}$
Power delivered to load $\mathbf{= V I_L}$



<u>E.M.F. Equation OF A D.C. Generator</u>:

We shall now derive an expression for the e.m.f. generated in a D.C. generator.

Let, ϕ = flux/pole in Wb
Z = total number of armature conductors
P = number of poles
A = number of parallel paths
= **2 …..** For wave winding
= **P …..** For lap winding
N = speed of armature in r.p.m.
$\mathbf{E_g}$ **= e.m.f**. of the generator
= e.m.f./parallel path

Flux cut by one conductor in one revolution of the armature, $d\phi$ **= Pϕ (webers)**

As the conductor cuts the flux of all the P poles.

Time taken to complete one revolution,

$$\mathbf{dt = 60/N \text{ (seconds)}}$$

E.m.f. generated/conductor,

$$\frac{d\phi}{dt} = \frac{P\phi}{60/N} = \frac{P\phi N}{60} \quad \text{(volts)}$$

E.m.f. of generator, E_g = e.m.f. per parallel path

= (e.m.f./conductor) × No. of conductors/parallel path

$= \frac{P\phi N}{60} \times \frac{Z}{A}$

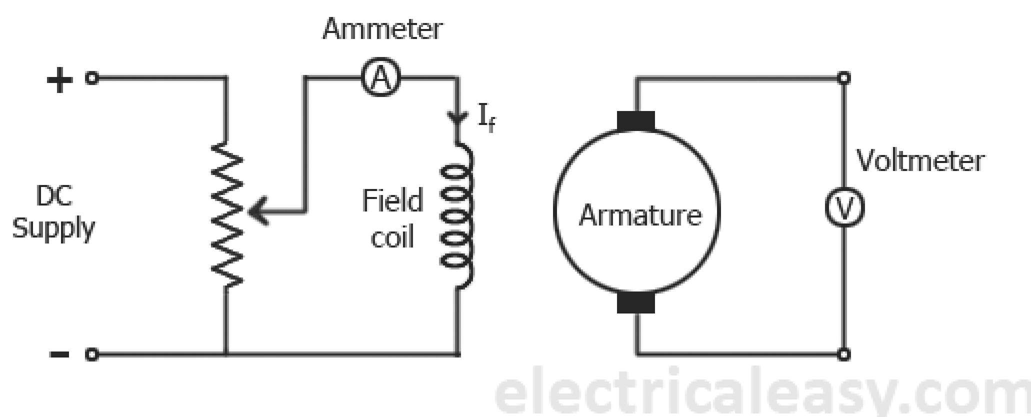
$$\boxed{E_g = \frac{\phi Z N}{60} \times \frac{P}{A}} \text{ volts}$$

Where **A = 2** ….. For wave winding **and** **A = P** ….. For lap winding

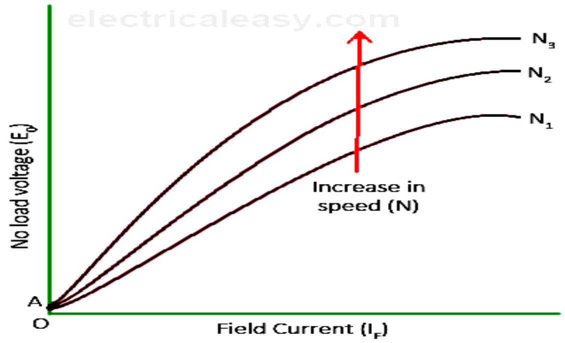
Generally, following three characteristics of DC generators are taken into considerations: (i) Open Circuit Characteristic (O.C.C.), (ii) Internal or Total Characteristic and (iii) External Characteristic.

Open Circuit Characteristic (O.C.C.) (E_0/I_f) of DC Shunt generator:

Open circuit characteristic is also known as magnetic characteristic or no-load saturation characteristic. This characteristic shows the relation between generated emf at no load (E_0) and the field current (I_f) at a given fixed speed. The O.C.C. curve is just the magnetization curve and it is practically similar for all type of generators. The data for O.C.C. curve is obtained by operating the generator at no load and keeping a constant speed. Field current is gradually increased and the corresponding terminal voltage is recorded. The connection arrangement to obtain O.C.C. curve is as shown in the figure below. For shunt or series excited generators, the field winding is disconnected from the machine and connected across an external supply.



Now, from the emf equation of dc generator, we know that Eg = kϕ. Hence, the generated emf should be directly proportional to field flux (and hence, also directly proportional to the field current). However, even when the field current is zero, some amount of emf is generated (represented by OA in the figure below). This initially induced emf is due to the fact that there exists some residual magnetism in the field poles. Due to the residual magnetism, a small initial emf is induced in the armature. This initially induced emf aids the existing residual flux, and hence, increasing the overall field flux. This consequently increases the induced emf. Thus, O.C.C. follows a straight line. However, as the flux density increases, the poles get saturated and the ϕ becomes practically constant. Thus, even we increase the I_f further, ϕ remains constant and hence, Eg also remains constant. Hence, the O.C.C. curve looks like the B-H characteristic



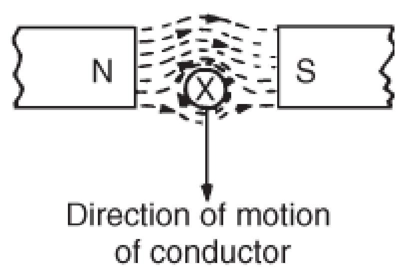
Open Circuit Characteristic (O.C.C.)

D.C. MOTORS

Introduction

An electric motor is a machine which converts electric energy to mechanical energy.
If a current-carrying conductor is placed in a magnetic field produced by permanent magnets, then the field due to the current carrying conductor and the permanent magnets interact and cause a force to be exerted on the conductor as shown in fig.
The force on the current-carrying conductor in a magnetic field is given by

Force $\boxed{F = BIl \sin\theta}$ Newton



Where, F = Force in Newton

B = Flux density in Weber/ m^2 or tesla

I = Current in amperes flowing through the conductor

l = Length of the conductor in meters

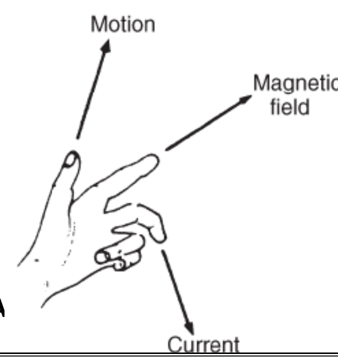
θ = angle between the direction of the field and current.

When the magnetic field, the current and the conductor are mutually at right angles then $\theta = 90^O$

Force $\boxed{F = BI\, l}$ Newton's

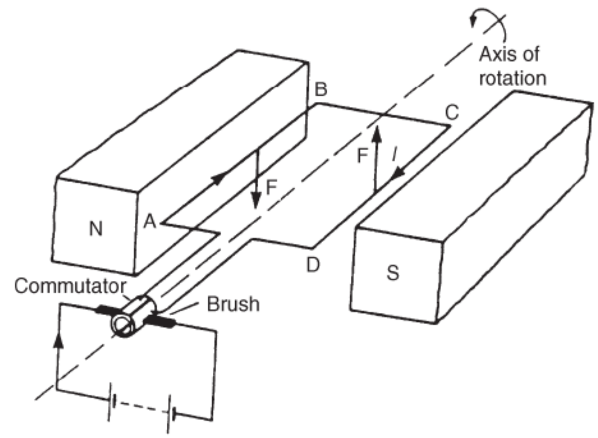
The field is strengthened above the conductor and weakened below, thus tending to move the conductor down wards. This is the basic principle of operation of the electric motor. The direction of the force exerted on a conductor can be predetermined by using **Fleming's left-hand rule** (often called the motor rule).

Fleming's Left Hand Rule: It states that "when the thumb, fore finger and middle finger are held mutually perpendicular to each other, with the fore finger in the direction of magnetic field, middle finger in the direction of the current, then the direction of thumb indicates the direction of force experienced by the conductor".



Principle of Operation of a Simple D.C Motor:

A rectangular coil which is free to rotate about a fixed axis shown placed inside a magnetic field produced by permanent magnets in fig. A direct current is fed into the coil via carbon brushes bearing on a Commutator, which consists of a metal ring split into two halves separated by insulation. When current flows in the coil a magnetic field is set up around the coil which interacts with the magnetic field produced by the magnets. This causes a force (F) to be exerted on the current-carrying conductor which by Fleming's left-hand rule, is down wards between point (A) and (B), upward between (C) and (D) for the current direction shown. This causes a torque and the coil rotates anticlockwise. When the coil has turned through (90^o) from the position shown in figure, the brushes connected to the positive and negative terminals of supply make contact with different halves of the Commutator ring, thus reversing the direction of the current flow in the conductor. If the current is not reversed and the coil rotates past this position the forces acting on it change direction and it rotates in the opposite direction thus never making more than half a revolution. The current direction is reversed every time the coil swing through the vertical position and thus the coil rotates anti-clockwise for as long as the current flows. This is the principle of operation of a D.C motor which is thus a device that takes in electrical energy and converts it into mechanical energy.



Significance of the Back e.m.f:

When the motor armature rotates, the conductors also rotate and hence cut the flux. In accordance with the laws of electromagnetic induction, e,m.f. is induced in them whose direction, as found by Fleming's Right-hand Rule, is in opposition to supplied voltage. Because of its opposing direction, it is referred to as counter e.m.f. or back e.m.f. (E_b).

It will be seen that

$$V = E_b + I_a R_a$$

$$I_a = \frac{V - E_b}{R_a}$$

Where (R_a) is the resistance of the armature circuit. As pointed out above

$$\boxed{E_b = \frac{\phi Z N}{60} \times \frac{P}{A}} \quad \text{volts}$$

Back e.m.f. depends, among other factors, upon the armature speed. If speed is high, E_b is large, hence armature current (I_a), as seen from the above equation, is small. If the speed is less, then (E_b) is less, hence more current flows which develops more torque. So, we find that (E_b) acts like a governor i.e. it makes a motor self-regulating so that it draws as much current as is just necessary.

Voltage equation of motor:

The voltage V applied across the motor armature has to

i) has to overcome the back e.m.f and

ii) supply the armature Ohmic drop I_aR_a

$$\boxed{V = E_b + I_a R_a}$$

This is known as voltage equation of a motor.

Now, multiplying both sides by I_a we get

$$\boxed{VI_a = E_bI_a + I_a^2R_a}$$

VI_a = electric input to the armature

E_bI_a = electric equivalent of mechanical power developed in the armature

$I_a^2R_a$ = Cu losses in the armature

Hence, output of the armature input, some is wanted in I^2R losses & rest is converted into mechanical power within the armature.

The efficiency is given by the ratio of power developed by the armature to its input

$$\frac{E_bI_a}{VI_a} = \frac{E_b}{V}$$

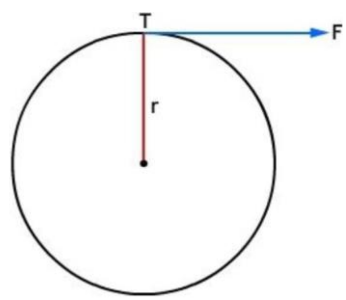
Torque:

By the term torque means the turning effect or twisting moment of a force about an axis. It is also equal to Force x Distance at which this force acts.

Torque $\boxed{T = F \times r}$ N-m

Work done by this force in one revolution = **force × distance**

= $F \times 2\pi r$ joules



Power developed = $F \times 2\pi r \times N$ watts

= $(F \times r) \times 2\pi N$

Since $\boxed{2\pi N = \omega}$ (Angular velocity in radians/sec)

Torque T= F × r

$\boxed{\text{Power developed} = T \times \omega}$ watts

If N is in rpm, then $\omega = 2\pi N/60$ rad/sec

Mechanical power developed:

$$\boxed{P_o = \frac{2\pi N}{60} \text{ x } T}$$

Armature Torque of a motor:

Let T_a be the torque developed by the armature of the motor running at **N** r.p.s.

If T_a is in N/M, then power developed = $T_a \times 2\pi N$ … (i)

We also know that electric power converted into mechanical power in the armature = E_bI_a Watts…… (ii)

Equating equations i &ii we get,

$$T_a \times 2\pi N = E_bI_a$$

Since $E_b = \frac{\phi ZN}{60} \text{ x } \frac{P}{A}$ volts

We have, $T_a \times 2\pi N = \frac{\phi ZN}{60} \text{ x } \frac{P}{A} I_a$ or

$$\boxed{T_a = \frac{\phi Z I_a}{2\pi} \times \frac{P}{A}} \text{ N-M}$$

$$\boxed{T_a = 0.159.\ \emptyset\ Z\ I_a \times \frac{P}{A}} \text{ N-M}$$

Shaft Torque:

The torque which is available for required useful work is known as Shaft Torque T_{sh}. It is so called because it is available at the shaft.

The motor output is given by

$$\textbf{Output} = T_{sh} \times 2\pi N \quad \text{Watts}$$

So, $T_{sh} = \frac{\text{output in watts}}{2\pi N}$ N-m in r.p.s

$= \frac{\text{output in watts}}{\frac{2\pi N}{60}}$ N-m in rpm

$= \frac{60 \times \text{output in watts}}{2\pi N}$

$= \frac{9.55 \times \text{output}}{N}$ N-m

The difference in the $\boxed{T_a - T_{sh}}$ is known as the lost torque & is due to iron & friction losses of the motor.

Losses in a D.C. Motor:

The losses occurring in a d.c. motor are the same as in a d.c. generator

These are:

- → **Copper losses** due to I^2R heat losses in the armature and field windings.
- → **Iron losses or magnetic (or core) losses** due to hysteresis and eddy-current losses in the armature. This loss can be reduced by constructing the armature of silicon steel laminations having a high resistivity and low hysteresis loss. At constant speed, the iron loss is assumed constant.
- → **Frication and Windage losses,** due to bearing and brush contact friction and losses due to air resistance against moving parts (called Windage). At constant speed, these losses are assumed to be constant.
- → **Brush contact loss** between the brushes and Commutator. This loss is approximately proportional to the load current.

As in a generator, these losses cause

(a) An increase of machine temperature and

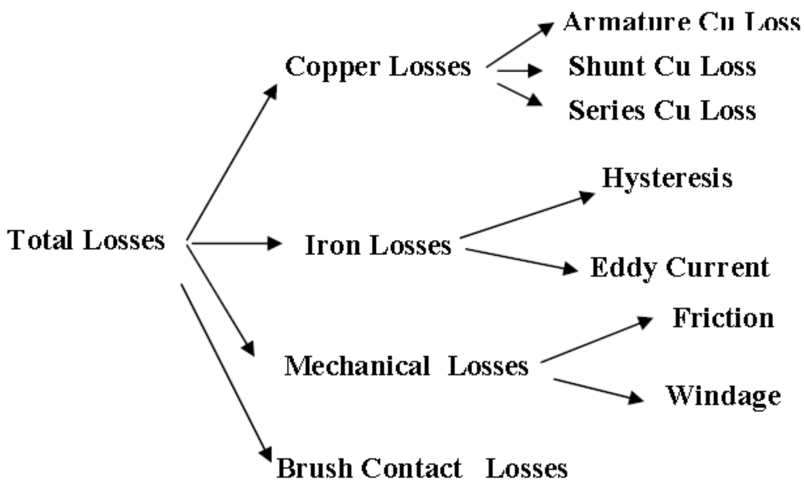
(b) Reduction in the efficiency of the D.C. motor.

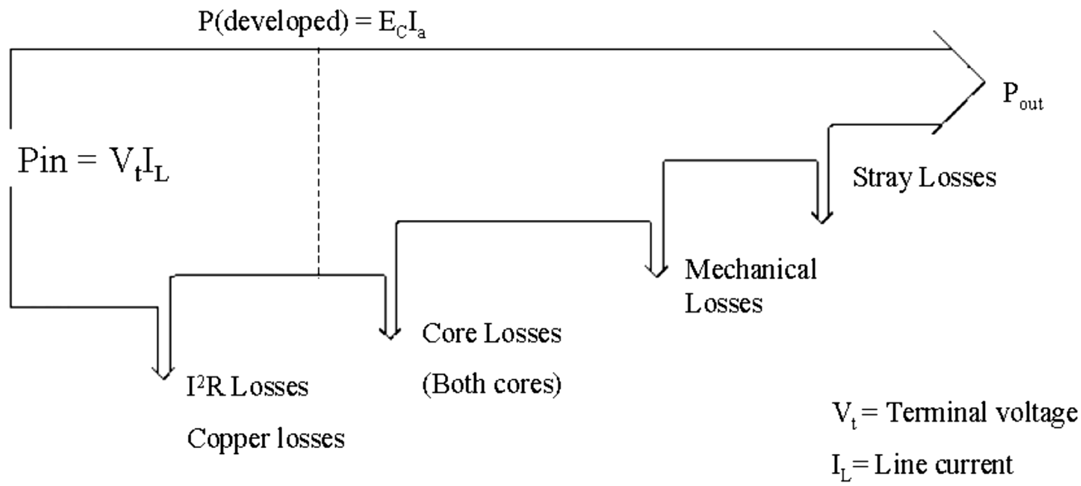
The following points may be noted:

(i) Armature Cu loss, field Cu loss and brush contact loss, Cu losses also occur

(ii) Since D.C. machines (generators or motors) are generally operated at constant flux density and constant speed, the iron losses are nearly constant.

(iii) The mechanical losses (i.e. friction and Windage) vary as the cube of the speed of rotation of the d.c. machine (generator or motor). Since D.C. machines are generally operated at constant speed, mechanical losses are considered to be constant.





Efficiency of A D.C. motor:

The efficiency of a D.C. motor is given by.

Efficiency, $\boxed{\eta = \dfrac{output \cdot power}{input \cdot power} \times 100\%}$

Also, the total losses $= I_a^2 R_a + I_f V + C$ (for a shunt motor) and,

total losses= $I^2 R + C$ (for a series motor),

Where C is the sum of the iron, Friction and Windage losses, R is the total resistance for series motor $R = (R_a + R_f)$

For a motor, the **input power =VI**

and the **output power= VI - losses**

Hence,

$$\eta = \left(\frac{VI - I_a^2 R - I_f V - C}{VI}\right) \times 100\,\% \qquad \text{(for shunt motor)}$$

$$\eta = \left(\frac{VI - IR - C}{VI}\right) \times 100\,\% \qquad \text{(for series motor)}$$

The efficiency of a motor is a maximum when the load is such that

(For shunt motor), (For series motor)

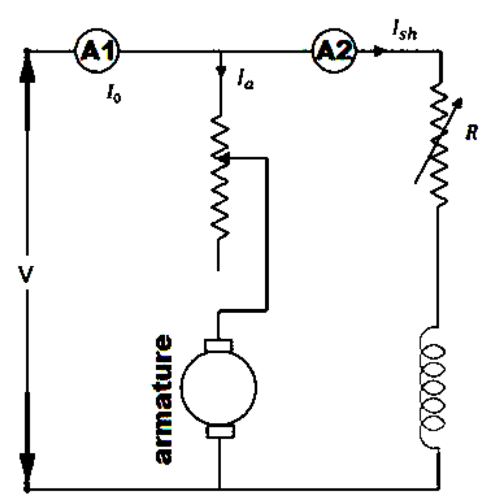
$$I_a^2 R_a = I_f V + C \qquad\qquad I^2 R = C$$

Swinburne's test:

This method is an indirect method of testing a dc machine. It is named after Sir James Swinburne. Swinburne's test is the most commonly used and simplest method of testing of shunt and compound wound dc machines which have constant flux. In this test the efficiency of the machine at any load is pre-determined. We can run the machine as a motor or as a generator. In this method of testing no load losses are measured separately and eventually we can determine the efficiency.

- For a d.c shunt motor change of speed from no load to full load is quite small.
- Therefore, mechanical loss can be assumed to remain same from no load to full load.
- Also if field current is held constant during loading,
- The core loss too can be assumed to remain same.
- In this test, the motor is **run at rated speed** under **no load condition at rated voltage**.
- The current drawn from the supply $\mathbf{I_0}$ and the field current $\mathbf{I_{sh}}$ is recorded.
- The circuit connection for Swinburne's test is shown in figure below. The speed of the machine is adjusted to the rated speed with the help of the shunt regulator R as shown in figure.

Calculation of Efficiency



Connection Diagram of Swinburne's Test

Let, $\mathbf{I_0}$: the no load current (it can be measured by ammeter A_1)

$\mathbf{I_{sh}}$: the shunt field current (it can be measured by ammeter A_2)

Then, no load armature current

$$\boxed{\mathbf{I_a = (I_0 - I_{sh})}}$$

Also let, **V** is the supply voltage.

Therefore, $\boxed{\textbf{No load power input} = \mathbf{VI_0}}$ Watts.

In Swinburne's test no load power input is only required to supply the losses. The losses occur in the machine mainly are:

- Iron losses in the core
- Friction and windings losses
- Armature copper loss.

Since the no load mechanical output of the machine is zero in Swinburne's test, the no load input power is only used to supply the losses.

The value of **armature copper loss = $\boxed{(I_0 - I_{sh})^2 R_a}$**

Here, **R_a is the armature resistance**.

Now, to get the constant losses we have to subtract the armature copper loss from the no load power input.

Then, **$\boxed{\text{Constant losses } W_C = VI_0 - (I_0 - I_{sh})^2 R_a}$**

After calculating the no load constant losses now we can determine the efficiency at any load.

Let, **I** is the load current at which we have to calculate the efficiency of the machine.

Then, when the machine is motoring

Armature current $\boxed{(I_a) = (I - I_{sh})}$,.

And $I_a = (I + I_{sh})$, when the machine is generating**.**

Calculation of Efficiency When the Machine Is Motoring On Load

Power input = VI

Armature copper loss, $P_{CU} = I^2 R_a = (I - I_{sh})^2 R_a$

Constant losses, $W_C = VI_0 - (I_0 - I_{sh})^2 R_a$

Total losses = $P_{CU} + W_C$

∴ Efficiency of the motor:

$$\boxed{\eta_m = \frac{output}{input} = \frac{input - losses}{input} = \frac{VI - (P_CU + W_C)}{VI}}$$

Advantages of Swinburne's Test

- This test is very convenient and economical as it is required very less power from supply to perform the test.
- Since constant losses are known, efficiency of Swinburne's test can be pre-determined at any load.

Disadvantages of Swinburne's Test

- Iron loss is neglected though there is change in iron loss from no load to full load due to armature reaction.
- We cannot be sure about the satisfactory commutation.
- We can’t measure the temperature rise.
- Swinburne's test cannot be performed on dc series motor as it is a no load test.

Examples Problems:

A 440-V, shunt motor has armature resistance of 0.8 Ω and field resistance of 200 Ω. Determine the back e.m.f. when giving an output of 7.46 kW at 85 percent efficiency.

<u>Solution:</u> Motor input power = 7.46 × 103 /0.85 W

Motor input current = 7460/0.85 × 440 = 19.95 A ;

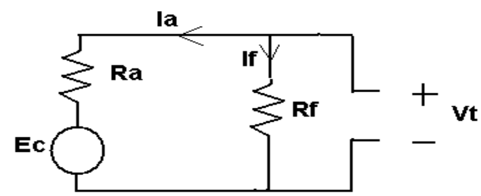
$I_{sh} = 440/200 = 2.2$ A $I_a = 19.95 - 2.2 = 17.75$ A ;

Now, $E_b = V - I_a R_a$ ∴ $E_b = 440 - (17.75 \times 0.8) = 425.8$ V

1. A 240 V, shunt DC motor takes an armature current of 20 A when running at 960 rpm. The armature resistance is 0.2 Ω. Determine the no load speed if the no load armature current is 1 A.

$$V_t = I_a R_a + E_c$$
$$\Rightarrow E_c \text{ (full load)} = 240 - 20 * 0.2 = 236 \text{ V}$$
$$E_c \text{ (no load)} = 240 - 1 * 0.2 = 239.8 \text{ V}$$
$$\text{assuming } I_f \text{ is constant}$$
$$\Rightarrow \frac{E_c(n.l.)}{E_c(F.l.)} = \frac{n(n.l.)}{n(F.l.)} \Rightarrow n(n.l.) = \frac{239.8}{236} * 960 = 975.45 \text{ rpm}$$

$$n.l. = \text{no load}, F.l. = \text{full load}$$



2. A 120 V shunt motor has the following parameters: Ra = 0.4 Ω, RF = 120 Ω and rotational core, mechanical and stray) losses are 240 W. On full load, the line current is 19.5 A and the motor runs at 1200 rpm, find the developed power, The output power, and The output torque.

$$(a) I_a = I_L - I_f$$
$$I_f = \frac{120}{120} = 1A \Rightarrow I_a = 19.5 - 1 = 18.5 \text{ A}$$
$$E_c = V_T - I_a R_a = 120 - (18.5) * (0.4) = 112.6 \text{ V}$$
$$P_{developed} = E_c * I_a = 112.6 * 18.5 = 2083.1 \text{ watt}$$
$$\text{(b) } P_{out} = P_{developed} - \textit{rotational losses} = 2083 - 240 = 1843 \text{ watt}$$
$$(c)\ \tau_{out} = \frac{P_{out}}{\omega} = \frac{1843}{\frac{2\pi}{60} 1200} = 14.67 \text{ N.m}$$

Speed control of Dc motor: For a Dc motor, we know

The magnitude of the back E.M.F is given by

E_b = (ϕZNP/60A) volts

The applied Voltage is given by

V = E_b + Ia Ra volts

From the above two equations

N = K (V-Ia Ra) / ϕ rpm

Where N = Speed of the motor in r.p.m

V = Supply Voltage

ϕ = Flux in Webers

Ra = Armature Resistance in ohms

The Speed of DC Motor depends on
1. Armature Resistance (Ra)
2. Applied Voltage (V)
3. Field Flux control (Φ)

Methods of Speed Control of DC Motors:
1. Armature control method
2. Field control method
3. Voltage control method

<u>For a dc shunt motor</u>

Armature control method (or) Rheostat control method: N α (V – IaRa) and N α E_b

- Variation of voltage across the armature varies the back e.m.f and hence the speed.
- Higher the voltage drop in armature winding lesser the back e.m.f and hence lesser the speed.
- Speeds below the rated value can be obtained.

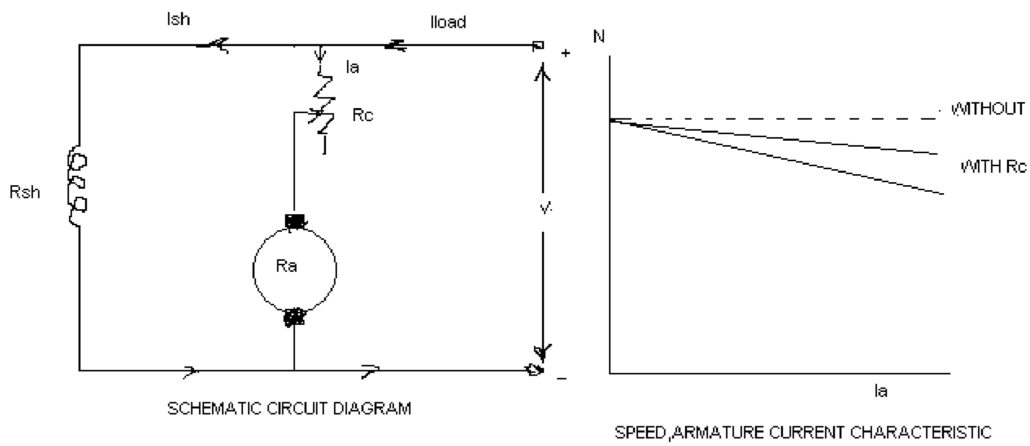


Fig : Armature control method (or) Rheostat control method

Flux control method: N α 1 / Φ

- Higher the flux lower will be the speed. Hence the speed can be varied by changing the flux.
- A variable resistance (shunt field rheostat) is placed in series with the shunt field winding.
- Shunt field rheostat reduces the shunt field current and hence the field flux by increasing resistance.
- Reduction in flux increases the speed of the motor.
- Speeds above the rated value can be obtained.

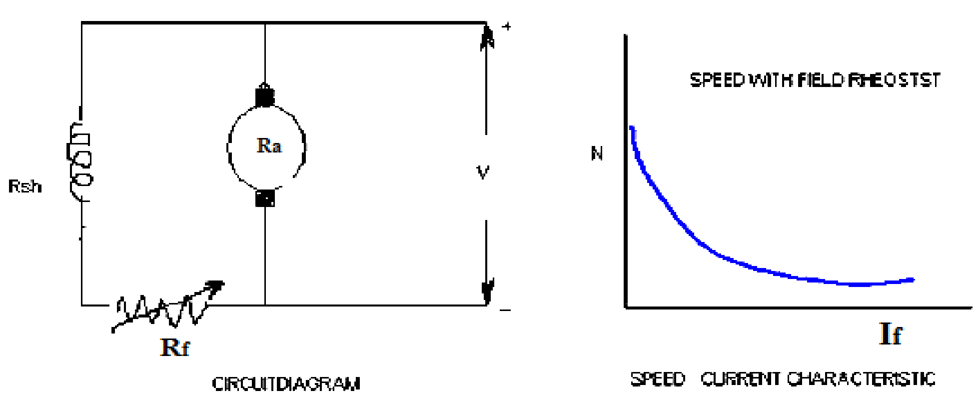
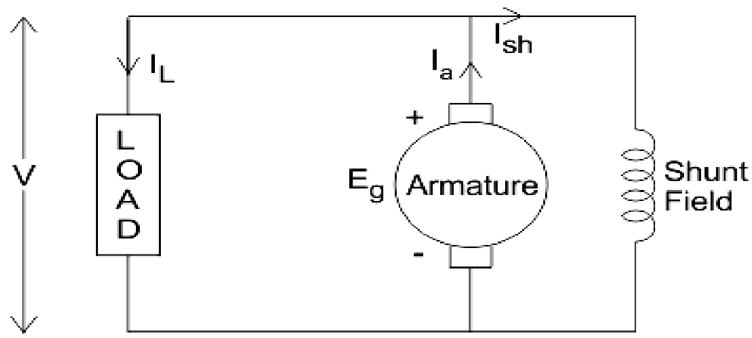


Fig: Field control method

Generally, following three characteristics of DC generators are taken into considerations: (i) Open Circuit Characteristic (O.C.C.), (ii) Internal or Total Characteristic (E/Ia) and (iii) External Characteristic (V/I_L)

Characteristic of Shunt Wound DC Generator

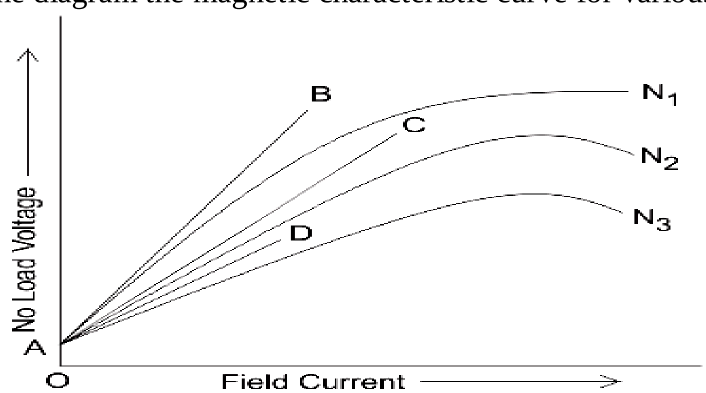
In shunt wound DC generators the field windings are connected in parallel with armature conductors as shown in figure below. In these type of generators the armature current I_a divides in two parts. One part is the shunt field current I_{sh} flows through shunt field winding and the other part is the load current I_L goes through the external load . $So,\ I_a = I_{sh} + I_L$



Shunt Wound Generator

Magnetic or Open Circuit Characteristic of Shunt Wound DC Generator or OCC

This curve is drawn between shunt field current(I_{sh}) and the no load voltage (E_0). For a given excitation current or field current, the emf generated at no load E_0 varies in proportionally with the rotational speed of the armature. Here in the diagram the magnetic characteristic curve for various speeds are drawn.



Magnetic or Open Circuit Characteristic

Due to residual magnetism the curves start from a point A slightly up from the origin O. The upper portions of the curves are bend due to saturation. The external load resistance of the machine needs to be maintained greater than its critical value otherwise the machine will not excite or will stop running if it is already in motion. AB, AC and AD are the slops which give critical resistances at speeds N_1, N_2 and N_3. Here, $N_1 > N_2 > N_3$.

Critical Load Resistance of Shunt Wound DC Generator

This is the minimum external load resistance which is required to excite the shunt wound generator.

UNIT-3 TRANSFORMER

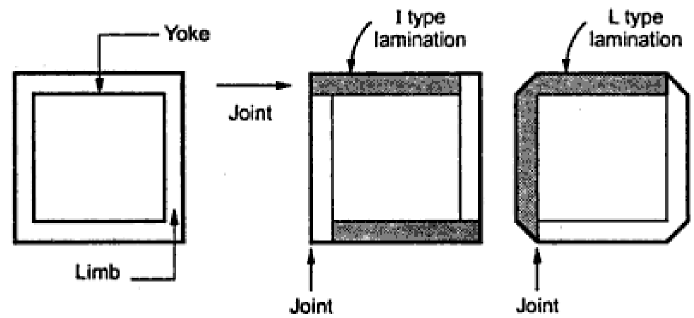
Transformer:

It is a static device which transfers electric energy from one electric circuit to another at any desired voltage without any change in frequency. It is used either for raising or lowering the voltage of an a.c. supply with a corresponding decrease or increase in current. It is a constant power device.

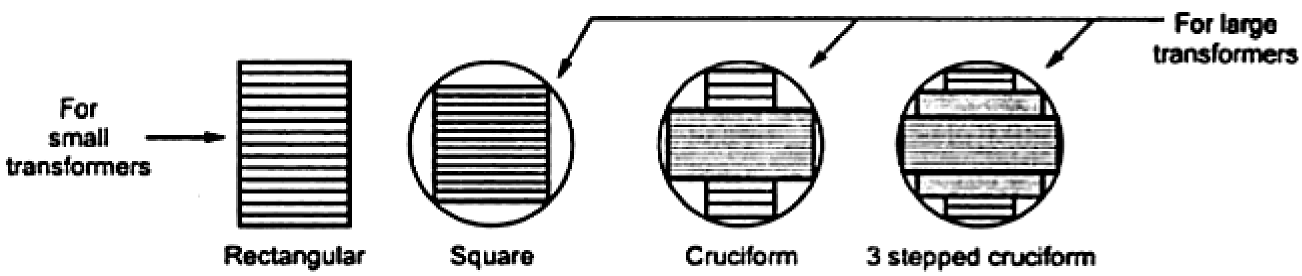
Construction of a Transformer:

The transformer consists of mainly two parts:

- Magnetic core
- Windings or coils.



It essentially consists of two windings, the primary and secondary, wound on a common laminated magnetic core as shown in Fig. The winding connected to the a.c. source is called primary winding (or primary) and the one connected to load is called secondary winding.



(i) The core is made of silicon steel which has low hysteresis loss and high permeability. Core is laminated in order to reduce eddy current loss. These features considerably reduce the iron losses and the no-load current.

(ii) Instead of placing primary on one limb and secondary on the other, it is usual practice to wind one-half of each winding on one limb. This ensures tight coupling between the two windings. Consequently, leakage flux is considerably reduced.

(iii) The winding resistances R_1 and R_2 are minimized to reduce I^2R loss and Resulting rise in temperature and to ensure high efficiency.

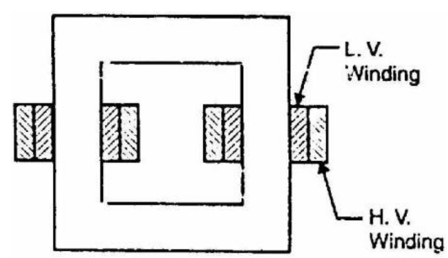
Based on construction the transformers are classified into two types.

$\rightarrow$ Core type transformer.

$\rightarrow$ Shell type transformer.

Core type:

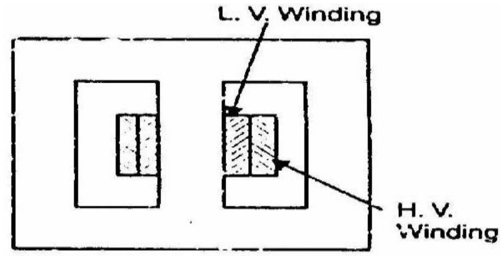
The coils used are form-wound and are of cylindrical type. The general form of these coils may be circular or oval or rectangular. In core type transformer, half of the primary winding and half of the secondary winding are placed round each limb as shown.



Core-type transformer

Shell type:

The coils are form-wound but are multi-layer disc type .The different layers of such multi-layer discs are insulated from each other by paper. The complete winding consists of stacked discs with insulation space between the coils. This method of construction involves the use of a double magnetic circuit. Both the windings are placed round the central lime, the other two limbs acting simply as a low-reluctance flux path.



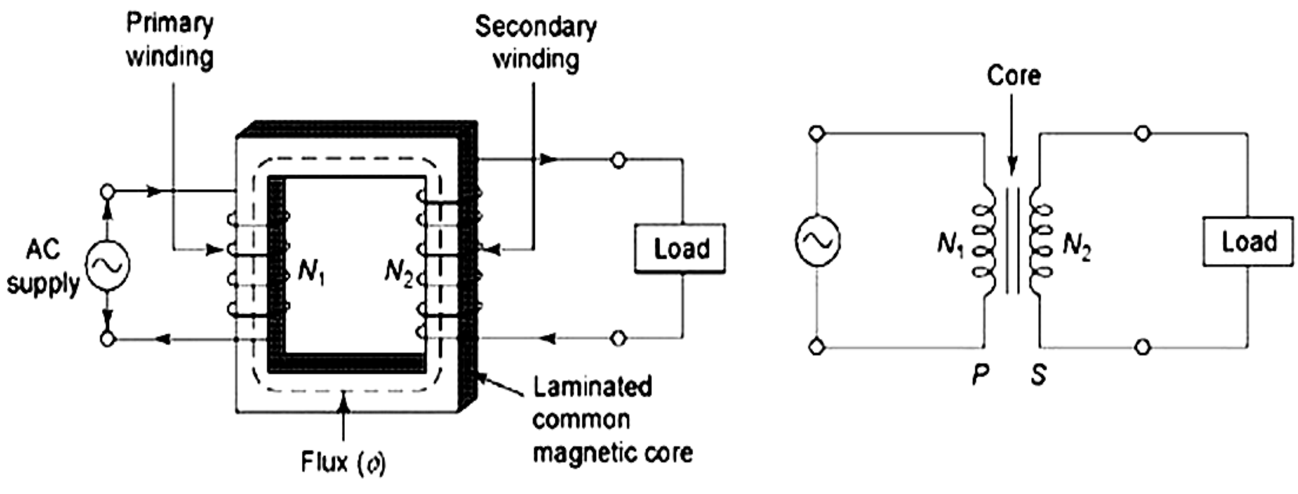
Shell-type transformer

Comparison between Core-type and Shell-type transformers:

	Core Type	Shell Type
1.	The winding encircles the core.	The core encircles most part of the winding.
2.	It has single magnetic circuit.	It has a double magnetic circuit.
3.	The core has two limbs.	The core has three limbs.
4.	The cylindrical coils are used.	The multilayer disc or sandwich type coils are used.
5.	The windings are uniformly distributed on two limbs hence natural cooling is effective.	The natural cooling does not exist as the windings are surrounded by the core.
6.	The coils can be easily removed from maintenance point of view.	The coils can not be removed easily.
7.	Preferred for low voltage transformers.	Preferred for high voltage transformers.

<u>Principle of operation:</u>

A transformer works on the principle of **Mutual Induction**.



(a) Basic transformer (b) Symbolic representation

When an alternating voltage V_1 is applied to the primary, an alternating flux f is set up in the core. This alternating flux links both the windings and induces e.m.f.s E_1 and E_2 in them according to Faraday's laws of electromagnetic induction. The e.m.f. E_1 is termed as primary e.m.f. and e.m.f. E_2 is termed as secondary e.m.f. This induced e.m.f. E_2 in the secondary causes a secondary current I_2. Consequently, terminal voltage V_2 will appear across the load.

$$\text{Clearly,} \qquad E_1 = -N_1 \frac{d\phi}{dt}$$

$$\text{and} \qquad E_2 = -N_2 \frac{d\phi}{dt}$$

$$\therefore \qquad \frac{E_2}{E_1} = \frac{N_2}{N_1}$$

Magnitudes of E_2 and E_1 depend upon the number of turns on the secondary and primary respectively. If load is connected across the secondary winding, the secondary e.m.f. E_2 will cause a current I_2 to flow through the load. Thus, a transformer enables us to transfer a.c. power from one circuit to another with a change in voltage level.

→ If $N_2 > N_1$, then $E_2 > E_1$ (or $V_2 > V_1$) and we get a step-up transformer.
→ If $N_2 < N_1$, then $E_2 < E_1$ (or $V_2 < V_1$) and we get a step-down transformer.
→ If $N_2 = N_1$, then $E_2 = E_1$ (or $V_2 = V_1$) and we get an isolation or one-to-one transformer.

The following points may be noted carefully:

(i) The transformer action is based on the laws of electromagnetic induction.
(ii) There is no electrical connection between the primary and secondary. The a.c. power is transferred from primary to secondary through magnetic flux.
(iii) There is no change in frequency i.e., output power has the same frequency as the input power.
(iv) The losses that occur in a transformer are:
(a) Core losses—eddy current and hysteresis losses
(b) Copper losses—in the resistance of the windings

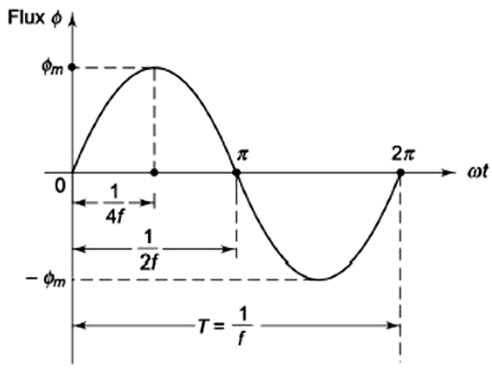
A transformer has very high efficiency. Because the losses are very small so that output power is nearly equal to the input primary power.

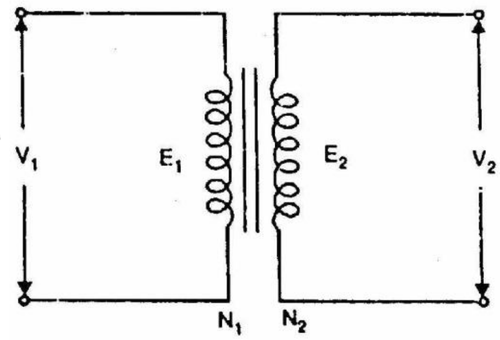
EMF Equation:

Whenever a coil is subjected to alternating flux, there will be an induced emf in it and is called the statically induced emf $e = \frac{Nd\phi}{dt}$

Let N_1, N_2 be the no. of turns of the primary and secondary windings,
Consider that an alternating voltage V_1 of frequency f is applied to the primary as shown in Fig.below
The sinusoidal flux ϕ produced by the primary can be represented as:

$$\Phi = \Phi_m \sin\omega t$$





The instantaneous e.m.f. e_1 induced in the primary is:

It is clear from the above equation that maximum value of induced e.m.f. in the primary is:

$$E_{m1} = 2\pi f \phi_m N_1$$

The R.M.S. value of the primary e.m.f. is:

$$e_1 = -N_1 \frac{d\phi}{dt} = -N_1 \frac{d}{dt}(\phi_m \sin \omega t)$$

$$= -\omega N_1 \phi_m \cos \omega t = -2\pi f N_1 \phi_m \cos \omega t$$

$$= 2\pi f N_1 \phi_m \sin(\omega t - 90°)$$

$$E_1 = \frac{E_{m1}}{\sqrt{2}} = \frac{2\pi f N_1 \phi_m}{\sqrt{2}}$$

or $\quad E_1 = 4.44 f N_1 \phi_m$

Similarly $\quad E_2 = 4.44 f N_2 \phi_m$

Note. It is clear from above that e.m.f. E_1 induced in the primary lags behind the flux Φ by 90°. Likewise, e.m.f. E_2 induced in the secondary lags behind flux Φ by 90°.

Voltage Transformation Ratio (K): From the above equations of induced e.m.f., we have

$$\boxed{\frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{V_2}{V_1} = K = \frac{I_1}{I_2}}$$

Assuming to be an ideal transformer where:

(i) $E_1 = V_1$ and $E_2 = V_2$ as there is no voltage drop in the windings.

(ii) There are no losses. Therefore, volt-amperes input to the primary are equal to the output volt-amperes i.e. $V_1 I_1 = V_2 I_2$

Hence, currents are in the inverse ratio of voltage transformation ratio. This simply means that if we raise the voltage, there is a corresponding decrease of current.

Losses and Efficiency:

There two types of power losses that occur in a transformer. They are:

1**) Core loss** **2) Copper loss**

1) Core loss:

This is the power loss that occurs in the core part. they are also called as iron loss because the core is made of iron material which is magnetic in nature. This loss is due to the alternating frequency of the emf. Iron loss in further classified into two other losses.

a) Eddy current loss **b) Hysteresis loss**

a) Hysteresis Loss:

This is the loss in the iron core, due to the magnetic reversal of the flux in the core, which results in the form of heat in the core. This loss is directly proportional to the supply frequency.

$$\boxed{W_h = K_h\, B_{\max}^{1.6}\, f}$$

Hysteresis loss can be minimized by using the core material having high permeability.

b) **Eddy Current Loss:**

This power loss is due to the alternating flux linking the core, which will induced an emf in the core called the eddy emf, due to which a current called the eddy current is being circulated in the core. As there is some resistance in the core with this eddy current circulation converts into heat called the eddy current power loss. Eddy current loss is proportional to the square of the supply frequency.

$$\boxed{W_e = K_e\, B_{\max}^{2}\, f^{2}}$$

Eddy current loss can be minimized by using the core made of thin sheets of silicon steel material, and each lamination is coated with varnish insulation to suppress the path of the eddy currents.

Both hysteresis and eddy current losses depend upon:

(i) Maximum flux density B_{max} in the core and

(ii) Supply frequency f. Since transformers are connected to constant-frequency, constant voltage supply, both f and B_m are constant. Hence, core or iron losses are practically the same at all loads.

Iron or Core losses, W_C = Hysteresis loss (W_h) + Eddy current loss (W_e) = Constant losses (W_c)

2) Copper loss:

This is the power loss that occurs in the primary and secondary coils when the transformer is on load. This power is wasted in the form of heat due to the resistance of the coils. This loss is proportional to the sequence of the load hence it is called the Variable loss.

The total copper losses: $W_{cu} = I_1^2 R_1 + I_2^2 R_2$

$$W_{cu} = I_1^2 R_{01} = I_2^2 R_{02}$$

It is clear that copper losses vary as the square of load current.

Total losses in a transformer = Constant losses + Variable losses.

$$\boxed{W_t = W_c + W_{cu}}$$

Efficency:

It is the ratio of the output power to the input power of a transformer.

$$\boxed{\eta = \frac{\textbf{Output Power}}{\textbf{Input Power}}}$$

Input = Output + Total losses

= Output + Iron loss + Copper loss.

Efficiency =

$$\eta = \frac{outputpower}{outputpower + coreloss + copperloss}$$

$$= \frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + W_{core} + W_{copper}}$$

Where, **V_2** is the secondary (output) voltage,

I_2 is the secondary (output) current and

Cosϕ is the power factor of the load.

The transformers are normally specified with their ratings as KVA,

Therefore,

$$\eta = \frac{\text{KVA} \quad \cos\Phi}{\text{KVA} \quad \cos\Phi + W_{core} + W_{copper}}$$

Since the copper loss varies as the square of the load the efficiency of the transformer at any desired load x is given by

$$\eta = \frac{\text{x KVA} \quad \cos\Phi}{\text{x KVA} \quad \cos\Phi + W_{core} + x^2 W_{copper}}$$

Where W_{copper} is the copper loss at full load

$W_{copper} = I^2R$ watts

Condition for maximum efficiency:

In general for the efficiency to be maximum for any device the losses must be minimum. Between the iron and copper losses the iron loss is the fixed loss and the copper loss is the variable loss. When these two losses are equal and also minimum the efficiency will be maximum.

Therefore the condition for maximum efficiency in a transformer is

Iron loss = Copper loss

Voltage Regulation:

The voltage regulation of a transformer is defined as the change in the secondary terminal voltage between no load and full load, expressed as a percentage of the no-load terminal voltage. Assuming that primary voltage and frequency to be constant. That is

$$\boxed{\%\ \text{Voltage regulation} = \frac{\text{noload secondary voltage} - \text{full load secondary voltage}}{\text{no load secondary voltage}} \text{X } 100}$$

also the regulation can be expressed as percentage of full-load terminal voltage.

$$\boxed{\%\ \text{Voltage regulation} = \frac{\text{noload secondary voltage} - \text{full load secondary voltage}}{\text{full load secondary voltage}} \text{X } 100}$$

Voltage regulation is a measure of the change in the terminal voltage of a transformer between No load and Full load. A good transformer has least value of the regulation of the order of ±5%.

Expression for Voltage Regulation of Transformer:

An electrical power transformer is open circuited means load is not connected with secondary terminals. In this situation the secondary terminal voltage of the transformer will be its secondary induced emf E_2. Whenever full load is connected to the secondary terminals of the transformer, rated current I_2 flows through the secondary circuit and voltage drops occurs at load. So, primary winding will also draw equivalent full load current from source. The voltage drop in the secondary is I_2Z_2 where Z_2 is the secondary impedance of transformer. If now, at this loading condition the voltage between secondary terminals V_2 across load terminals will be obviously less than no load secondary voltage E_2 and this is because of I_2Z_2 voltage drop in the transformer.

% Voltage regulation = $\frac{V_{02}-V_2}{V_2}$ x 100

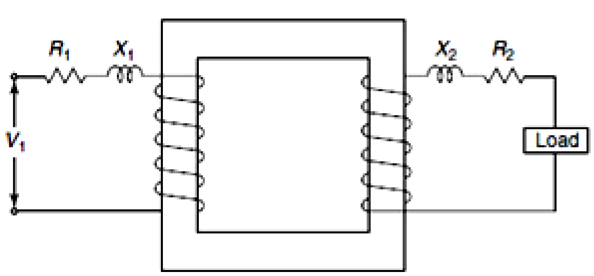
Where $V_{02} = E_2$ the no-load secondary voltage of the transformer.

Voltage Regulation of transformer at **lagging power factor:**

$$\%\ \text{regulation} = \frac{V_{02} - V_2}{V_{02}} \text{ x } 100 = \frac{I_2R_2\text{Cos}\Theta_2 + I_2X_2\text{Sin}\Theta_2}{V_{02}} \text{ x } 100$$

Voltage Regulation of transformer at **leading power factor:**

$$\%\ \text{regulation} = \frac{V_{02} - V_2}{V_{02}} \text{ x } 100 = \frac{I_2R_2\text{Cos}\Theta_2 - I_2X_2\text{Sin}\Theta_2}{V_{02}} \text{ x } 100$$



Equivalent Circuit

Testing of transformers:

Large scale transformers are tested indirectly by using open circuit and short circuit tests. In this the transformer is not loaded. So no loading device is required and large power is not wasted in testing, but more calculations are involved. By conducting these tests we can determine:

- Parameters of equivalent circuit.
- Regulation at any desired load and power factor.
- Losses and efficiency at any desired load and power factor.

Open Circuit Test:

The connection diagram for **open circuit test on transformer** is shown in the figure. A voltmeter, wattmeter, and an ammeter are connected in LV side of the transformer as shown.

- The voltage at rated frequency is applied to that LV side with the help of a variac.
- The HV side of the transformer is kept open.
- Now with help of variac applied voltage is slowly increase until the voltmeter gives reading equal to the rated voltage of the LV side.
- After reaching at rated LV side voltage, all three instruments reading (Voltmeter, Ammeter and Wattmeter readings) are recorded.
- The ammeter reading gives the no load current I_o. As no load current Io is quite small compared to rated current of the transformer, the voltage drops due to this electric current then can be taken as negligible.
- Voltmeter reading V_1 can be considered equal to secondary induced voltage of the transformer.
- The input power during test is indicated by watt-meter reading. As the transformer is open circuited, there is no output hence the input power here consists of core losses in transformer and copper loss in transformer during no load condition. But as said earlier, the no load current in the transformer is quite small compared to full load current so copper loss due to the small no load current can be neglected. Hence the wattmeter reading can be taken as equal to core losses in transformer. Let us consider wattmeter reading is P_o.

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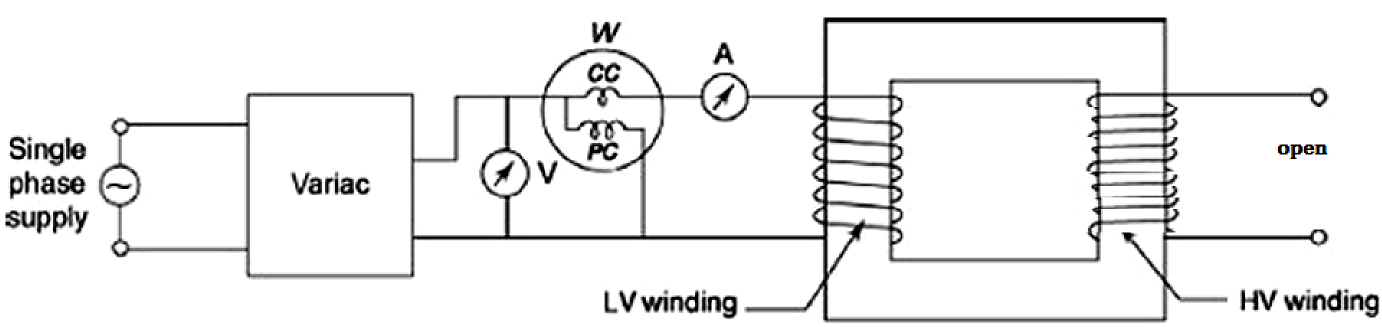
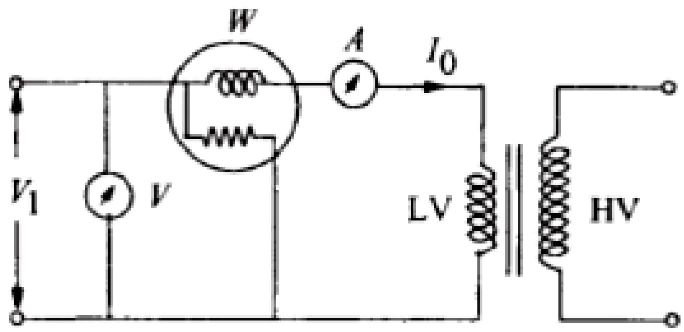
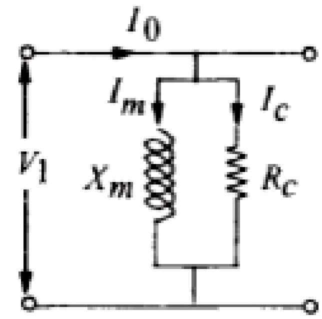




(a)



(b)

Iron losses, W_i = Wattmeter reading = W_0
No load current = Ammeter reading = I_0
Applied voltage = Voltmeter reading = V_1
Input power, $W_0 = V_1 I_0 \cos \phi_0$
Therefore

$$\text{No - load p.f.,} \quad \cos\phi_0 = \frac{W_0}{V_1} I_0$$

$$I_W = I_0 \cos\phi_0; \qquad I_m = I_0 \sin\phi_0$$

$$R_0 = \frac{V_1}{I_W} \quad \text{and} \quad X_0 = \frac{V_1}{I_m}$$

The **open circuit test on transformer** is used to determine core losses in transformer and parameters of shunt branch of the equivalent circuit of transformer.

Short circuit test:

The connection diagram for **short circuit test on transformer** is shown in the figure. A voltmeter, wattmeter, and an ammeter are connected in HV side of the transformer as shown.

- The voltage at rated frequency is applied to that HV side with the help of a variac
- The LV side of the transformer is short circuited.
- Now with help of variac applied voltage is slowly increase until the ammeter gives reading equal to the rated current of the HV side.
- After reaching at rated current of HV side, all three instruments reading (Voltmeter, Ammeter and Watt-meter readings) are recorded.
- The ammeter reading gives the primary equivalent of full load current I_L.
- As the voltage, applied for full load current in short circuit test on transformer, is quite small compared to rated primary voltage of the transformer, the core losses in transformer can be taken as negligible.

- Voltmeter reading is V_{sc}. The input power during test is indicated by watt-meter reading. As the transformer is short circuited, there is no output hence the input power here consists of copper losses in transformer.
- Since, the applied voltage V_{sc} is short circuit voltage in the transformer and hence it is quite small compared to rated voltage so core loss due to the small applied voltage can be neglected. Hence the wattmeter reading can be taken as equal to copper losses in transformer. Let us consider wattmeter reading is W_{sc}.

Full load Cu loss, P_C = Wattmeter reading = W_{Sc}

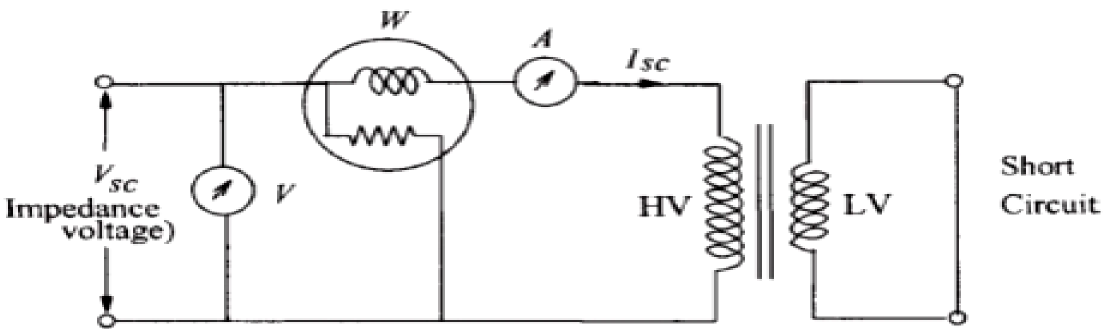
Applied voltage = Voltmeter reading = V_{SC}

F.L. primary current = Ammeter reading = I_1

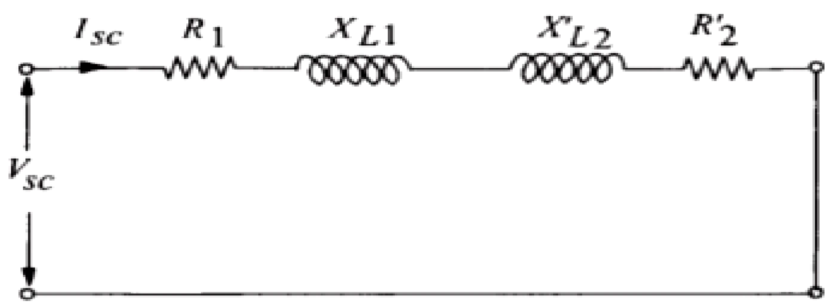
$$P_C = I_1^2 R_1 + I_1^2 R'_2 = I_1^2 R_{01}$$

$$\therefore \quad R_{01} = \frac{P_C}{I_1^2}$$

Where R_{01} is the total resistance of transformer referred to primary.



(a)



(b)

Total impedance referred to primary, $Z_{01} = \frac{V_{SC}}{I_1}$

Total leakage reactance referred to primary, $X_{01} = \sqrt{Z_{01}^2 - R_{01}^2}$

Short-circuit p.f, $\cos\phi_2 = \frac{P_C}{V_{SC} I_1}$

Thus short-circuit lest gives full-load Cu loss, R_{01} and X_{01}.

Note:

The short-circuit test will give full-load Cu loss only if the applied voltage VSC is such so as to circulate full-load currents in the windings. If in a short-circuit test, current value is other than full-load value, the Cu loss will be corresponding to that current value.

Advantages of Transformer Tests:

- ✓ The above two simple transformer tests offer the following advantages:
- ✓ The power required to carry out these tests is very small as compared to the full-load output of the transformer. In case of open-circuit lest, power required is equal to the iron loss whereas for a short-circuit test, power required is equal to full-load copper loss.
- ✓ These tests enable us to determine the efficiency of the transformer accurately at any load and p.f. without actually loading the transformer.
- ✓ The short-circuit test enables us to determine R01 and X01 (or R02 andX02). We can thus find the total voltage drop in the transformer as referred to primary or secondary. This permits us to calculate voltage regulation of the transformer.

Previous Questions:

Nov-2010:

1) Explain the constructional details of single phase transformer.
2) A single phase transformer working at unity power factor has an efficiency of 90% at both half load and at full load of 600W. Determine the efficiency at 80% of full load.
3) 2. Explain the tests to be conducted to determine copper and iron losses with neat circuit diagram.
4) A 3300/220V, 30KVA, single phase transformer takes a no load current of 1.5A when the low voltage winding is open. The Iron loss component is 0.4A. Find
   (i) No load input power.
   (ii) Magnetizing component.
   (iii)Power factor of no load current.
5) Define efficiency and regulation of transformer. Explain the tests to be conducted to predetermine the efficiency and regulation with neat diagrams. (May-2011)

Nov-2011

6) Explain the principle of operation of a single – phase transformer when it supplies lagging power factor load.
7) Derive the emf equation of a single phase transformer and draw the no load phasor diagram
8) What is an ideal transformer and derive an expression for induced emf in a single phase transformer. Also explain its constructional details with neat diagram.
9) A 500 -KVA, 3-phase 50 Hz Transformer has a voltage Ratio (line voltages) of 33/11 KV and is Delta/Star connected. The resistances per phase are: High voltage 35 V, low voltage 876 V and the Iron loss is 3050 W. Calculate the efficiency at full load and one-half of full load respectively (a) at unity PF (b) 0.8 PF.

10) Discuss the constructional details of single - phase transformer and hence obtain the expression induced emf of a transformer.
11) Discuss the constructional features of transformers. Draw neat diagrams.
12) Calculate the flux in the core of a single – phase transformer having a primary voltage of 230 V, at 50 Hz and 50 turns. IF the flux density in the core is 1 Tesla, calculate the net cross – sectional area of the core.
13) The maximum flux density in the core of 250 /3000 Volts 50 HZ single phase transformer is 1.2 webers per square meter. If the emf per turn is 8 volts determine primary and secondary turns and area of the core.

Three phase Induction Motors

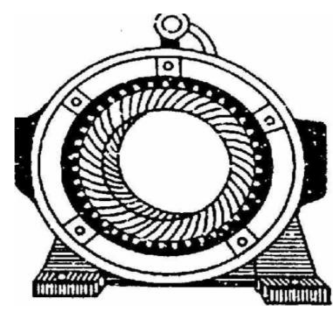
Introduction:

An electrical motor is an electromechanical device which converts electrical energy into a mechanical energy. In case of three phase AC operation, most widely used motor is **three phase induction motor** as this type of motor does not require any starting device or we can say they are self starting induction motor.

AC motors can be classified into two type i) Synchronous motors ii) Asynchronous motors. Induction motor is an asynchronous ac motor which converts input electrical energy into an output mechanical energy based on the principle of ***'Electromagnetic induction'***. Induction motor is an **asynchronous** motor as the speed of this motor is always other than synchronous speed. Induction motor consists of a stator and rotor like a transformer with primary and secondary windings. Induction motor is rotating device where as the transformer is a stationary device. Thus induction motor can be treated as ***'rotating transformer'***. Induction motor can be a single phase/three phase motor. Here we discuss the three phase induction motor.

Advantages of 3 phase IM:

- Very simple, extremely rugged and almost unbreakable construction especially squirrel cage type.
- Low cost and highly reliable
- high efficiency
- It has reasonably good power factor.
- Requires minimum maintenance
- It starts from rest and needs no extra starting mechanism.



Disadvantages of 3 phase IM:

- Speed can't be varied without scarifying some of it's efficiency.
- Speed decreases with increase in load.
- Starting torque is less compared to dc shunt motor.

Constriction details: Three phase induction motor consists of mainly two parts

I) Stationary Stator **II)** Rotating Rotor

Based on the rotor construction, 3-phase induction motors are classified as:

I . Squirrel cage type IM **II.** Slip-ring or wound rotor type or Phase wound type IM

STATOR:

Stator consisting of a steel frame that supports a hollow, cylindrical core.

Core is made as stacked silicon steel laminations having a number of evenly spaced slots, providing the space for the stator winding. Silicon steel laminations reduce hysteresis and eddy current losses of motor.

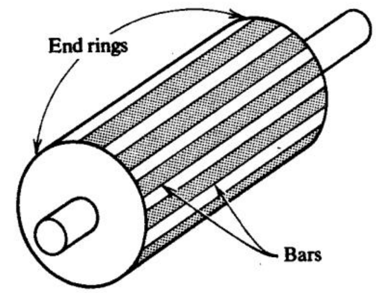
3phase stator windings are wound in the form of star/delta fashion in the slots. These stator windings are wound for a definite no. of poles based on the requirement of speed.

For example, to have 1500 rpm speed, Ns =120f/P-----> 1500=120*50/P -----> P=4

When 3-phase supply is given to the stator winding, a rotating magnetic field of constant magnitude is produced. This rotating field induces currents in the rotor by electromagnetic induction.

ROTOR: A revolving rotor mounted on a shaft composed of a series of laminated rotor slots that provides space for the rotor winding. The rotor is not connected electrically to the supply but has current induced in it by transformer action from the stator. Two basic design types depending on the rotor design.

Squirrel-cage rotor: Slots consists of heavy conducting bars of copper or aluminum and are shorted at both ends by end rings.



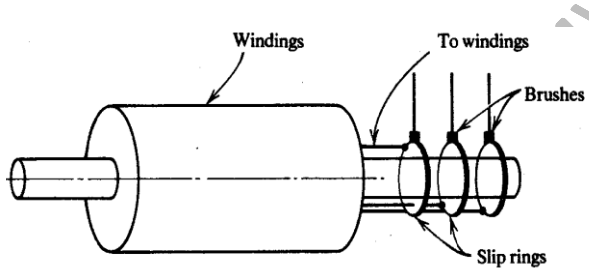
Advantage:

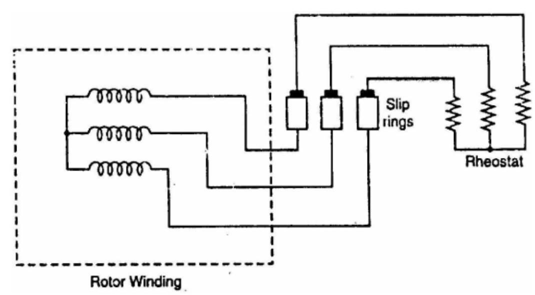
- Squirrel cage rotor has a remarkably simple and robust construction enabling it to operate in the most adverse circumstances.

Disadvantage:

- Low starting torque. It is because the rotor bars are permanently short circuited and it is not possible to add any external resistance to the rotor circuit to have a large starting torque.

Wound-rotor: Consists of three-phase windings (conducting wires) exactly as the stator and the ends of the three rotor wires are short circuited through 3 slip rings on the rotor shaft. The rotor winding is uniformly distributed in the slots and is usually star-connected. The open ends of the rotor winding are brought out and joined to three insulated slip rings mounted on the rotor shaft with one brush resting on each slip ring. The three brushes are connected to a 3-phase star-connected rheostat as shown in Fig. At starting, the external resistances are included in the rotor circuit to give a large starting torque. These resistances are gradually reduced to zero as the motor runs up to speed. The external resistances are used during starting period only. When the motor attains normal speed, the three brushes are short-circuited so that the wound rotor runs like a squirrel cage rotor.



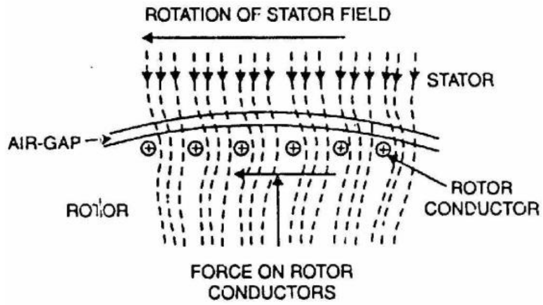


Principle of operation: Principle of operation is based on electro-magnetic induction. This is explained here. When the 3-phase stator windings are fed by a 3 – phase supply then 3 phase currents flows through windings which sets up a magnetic flux of constant magnitude but rotating at synchronous speed Ns (= 120 f/P).The flux passes through the air gap, cuts the rotor surface and so cuts the rotor conductors which are at stationary.

Due to the relative speed between the rotating flux and the stationary rotor conductors, an e.m.f.is induced in the rotor according to Faraday's laws of electro-magnetic induction. The frequency of the induced e.m.f. is the same as the supply frequency at starting. Its magnitude is proportional to the relative velocity between the flux and the conductors and its direction is given by Fleming's Right hand rule.

Since the rotor bars or conductors is a closed circuit, rotor current is produced whose direction, as given by Lenz's law, is such as a oppose the very cause producing it.

In this case, the cause which produces the rotor current is the relative velocity between the rotating flux of the stator and the stationary rotor conductors.
Hence, to reduce the relative speed, the rotor starts running in the same direction as that of the flux and tries to catch the rotating flux but it can't. The interaction of rotor current and rotating flux produces rotor torque that tends the rotor to rotate.



Slip: The IM will always run at a speed (Nr) lower than the synchronous speed (Ns).
The speed of the rotor relative to that of the stator rotating field is called 'slip'. The difference between the synchronous speed Ns and actual rotor speed Nr is called the 'Slip speed'.

1. Slip speed= Ns-Nr
2. Percentage slip % slip s = (Ns – Nr)/Ns x 100
3. Rotor (or motor) speed is Nr = Ns(1-s)
4. When the rotor is stationary (Nr =0), slip s=1 or (100%)
5. Slip varies as the load on the motor varies. If the load on the motor shaft increases, the rotor speed decreases the slip s increases. The induced e.m.f in rotor and rotor current increases to support the increase in load.
6. In an induction motor, the change in slip from no-load to full-load is hardly 0.1% to 3% so that it is essentially a constant-speed motor.

Frequency of rotor:
When the rotor is stationary, the frequency of rotor current is the same as the supply frequency.
But when the rotor starts revolving, then the frequency depends upon the relative speed or on slip Speed.

$$\boxed{f_r = s\, f_s}$$

When the rotor is blocked (Nr =0; s=1), the frequency of the induced voltage/rotor current is equal to the supply frequency.

On the other hand, if the rotor runs at synchronous speed (s = 0), the frequency will be zero.

Er = rotor induced e.m.f/phase under running state.
E_2= rotor induced e.m.f/phase at standstill state, s=1
Xr = rotor reactance/phase under running state. X_2= rotor reactance/phase at standstill state, s=1

$$\boxed{E_r = s\, E_2} \qquad \boxed{X_r = s\, X_2}$$

Torque equation of induction motor (Under Running Conditions):

$T \alpha\ \Phi\ I_r \cos \varnothing_2$ …… (i)

$T \alpha\ E_r\ I_r \cos \varnothing_2$ $(\ \therefore E_r\ \alpha\ \Phi)$

Where E_r = rotor e.m.f./phase under running condition

I_r = rotor current/phase under running conditions

Now $E_r = sE_2$

$\therefore \quad I_r = E_r/Z_r = sE_2/\sqrt{[R_2^2 + (sX_2)^2]}$

$\cos \varnothing_2 = R_2/\sqrt{[R_2^2 + (sX_2)^2]}$ ---From Fig. 1

Now equation (i) $T \alpha \Phi I_r \cos \varnothing_2$ ----> $T \alpha \Phi sE_2R_2/R_2^2 + (sX_2)^2 = k \Phi. s.E_2R_2/R_2^2 + (sX_2)^2$

$\therefore$ Where k is a proportionality constant

Also $T = k_1 s E_2^2R_2/R_2^2 + (sX_2)^2$ $(\therefore E_2 \alpha \Phi)$

Where k_1 is another constant. Its value can be proved to be equal to $3/(2 \Pi Ns)$ or $3/w_s$.

Hence, in that case, expression for torque becomes

$$\mathbf{T = (3/2\Pi Ns) (s E_2^2R_2)/ R_2^2 + (sX_2)^2}$$

Note:

1. At standstill, s = 1, obviously $T_{st} = (3/2\Pi Ns) (E_2^2R_2)/R_2^2 + (X_2)^2$
2. The condition of maximum torque T_{max} under running condition is $R_2 = sX_2$ and for max. stating torque is Tst is $R_2 = X_2$

Torque verses slip & Torque verses speed characteristics:

We know $T = k \Phi. s.E_2R_2 / R_2^2 + (sX_2)^2$

1. At speed close to synchronous (slip is low) the term sX_2 is small and so negligible compared to R_2. So then, we can write a relation as $T \alpha s /R_2$ or if R_2 constant then $T \alpha s$ hence for low values of slip the torque –slip curve is linear approximately.
2. When the speed is synchronous, slip s =0 the torque T =0, so the torque –slip curve starts from origin.
3. As the load on the shaft increases, the slip increases and so torque increases ,reaches maximum at slip s= R_2 / X_2 . The maximum torque is also called as break down torque or pullout torque.
4. After maximum torque , torque decreases with increase in slip $T \alpha 1/s$
5. Thus the torque –slip characteristics are of rectangular hyperbola in nature.

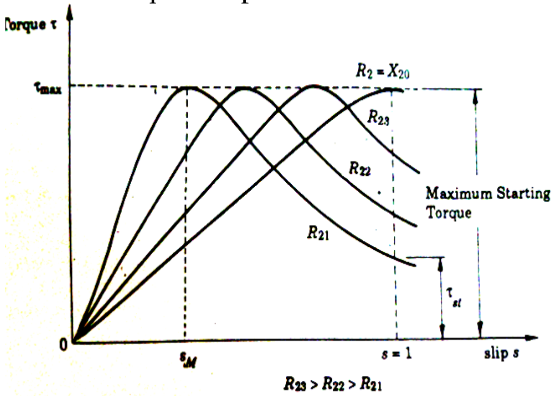


Fig. Torque-slip curves.

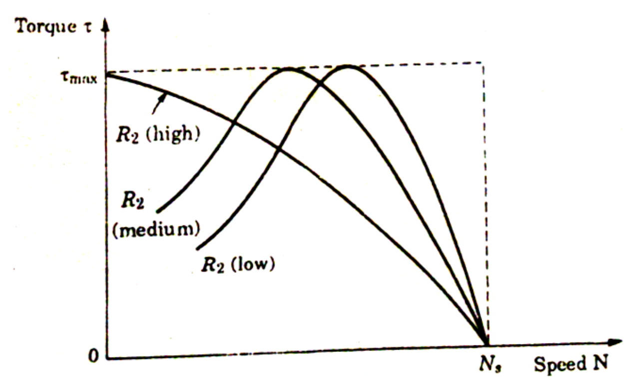


Fig. Torque-speed curves.

Applications of Induction Motor:

Induction motors are found everywhere from a small workshop to a large manufacturing industry.

1. **Squirrel Cage Motors :**Used in Fans, blowers, centrifugal pumps, line shafting tube-wells, flour mills
2. **Slip Ring Motors:** Preferred for lifts, hoists, elevators, cranes, compressors etc.

Unit -3.3
THREE PHASE ALTERNATORS

Syllabus: Principle of Operation-Constructional Details-EMF Equation.

Synchronous Machines

Rotating machines that rotate at a fixed speed (called synchronous speed) which depends up on supply frequency and no.of poles are called synchronous machines. Synchronous machines are of two types, synchronous generator and synchronous motor. A synchronous generator is a machine that converts mechanical power from a prime mover to ac electric power at a specific voltage and frequency. AC generators are usually called as alternators and also called as synchronous generators. Synchronous generators are usually of three phase type which is used in generating stations.

In Dc generators, the field poles are stationary and the armature is rotating. In Ac generators alternating emf will be generated in the conductor with field poles rotating past the stationary armature conductors.

Speed & frequency of output voltage:

Frequency of the generated alternating voltage depends up on no.of field poles and the speed at which field poles are rotated. $f= P.N /120$

At constant frequency, speed of the machine for various no.of poles is called synchronous speed,Ns.

>>> $f= P.N_s /120$ and $N_s=120f/P$

Use of Alternator

The power for the electrical system of a modern vehicle gets produced from an alternator. Another **use of alternators** is in diesel-electric locomotive. The engine of this locomotive is nothing but an alternator, driven by a diesel engine. The alternating current produced by this generator is converted to DC by integrated silicon diode rectifiers to feed all the DC traction motors. These DC traction motors drive the wheel of the locomotive.

Synchronous Machine Construction:

- Field :- carrying a DC excited winding
- Armature : three phase winding in which emf is generated
- Armature stationary and rotating field structure
- Armature winding is built of sheet-steel laminations having slots on its inner periphery
- Three phase winding is placed in these slots and serves as armature winding usually connected in star.
- Field is connected to an external source through slip rings and brushes or else receives excitation from rotating bodies
- Damper bars on the rotor: - it damps the oscillations due to transients.

Depending on rotor construction:-

- Round rotor type
  High speed machine such as turbine generators
- Salient pole type
  Low speed such as water wheel generator

Types of Alternator

AC generators (alternator) are of two **types** classified according to their design.

1. Salient pole type

   We use it as low and medium speed alternator. It has a large number of projecting poles having their cores bolted or dovetailed onto a heavy magnetic wheel of cast iron or steel of good magnetic quality. Such generators get characterized by their large diameters and short axial lengths. These generators look like a big wheel. These are mainly used for low-speed turbine such as in hydel power plant.

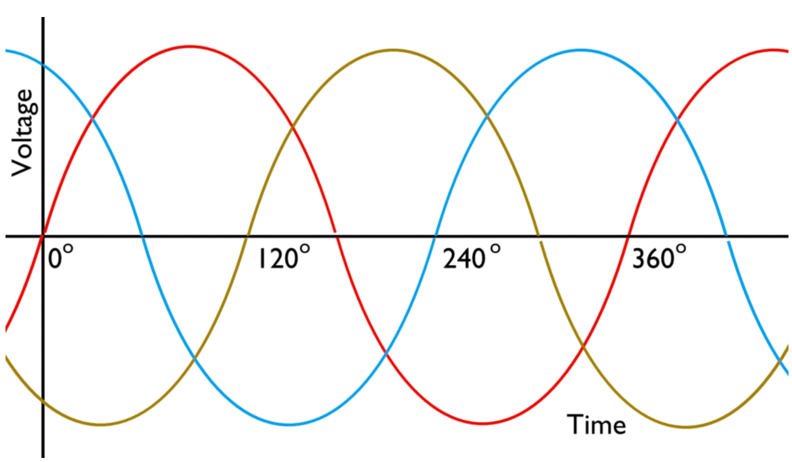
2. Smooth cylindrical type

   We use it for a steam turbine driven alternator. The rotor of this generator rotates at very high speed. The rotor consists of a smooth solid forged steel cylinder having certain numbers of slots milled out at intervals along the outer periphery for accommodating field coils. These rotors are designed mostly for 2 poles or 4 poles turbo generator running at 3600 rpm or 1800 rpm respectively.

Working Principle of Alternator

The **working principle of alternator** is very simple. It is just like basic principle of DC generator. It also depends upon Faraday's law of electromagnetic induction which says the current is induced in the conductor inside a magnetic field when there is a relative motion between that conductor and the magnetic field.

Generally in practical construction of alternator, armature conductors are stationary and field magnets rotate between them. The rotor of an alternator or a synchronous generator is mechanically coupled to the shaft or the turbine blades, which being made to rotate at synchronous speed N_s under some mechanical force results in magnetic flux cutting of the stationary armature conductors housed on the stator. As a direct consequence of this flux cutting an induced emf and current starts to flow through the armature conductors which first flow in one direction for the first half cycle and then in the other direction for the second half cycle for each winding with a definite time lag of 120° due to the space displaced arrangement of 120° between them as shown in the figure below. This particular phenomenon results in three phase power flow out of the alternator which is then transmitted to the distribution stations for domestic and industrial use.



Construction of Alternator

Similar to other rotating machines, an alternator consists of two main parts namely, the stator and the rotor. Stator is stationary part of the machine which carries the armature winding in which alternating voltage is generated. The rotor is rotating part which consists of field poles that produces a flux.

Stator: The various parts of the stator include the frame, stator core and stator windings. The stator core is laminated with silicon steel to reduce hysteresis and eddy current losses. Stator winding is usually star connected and distributed in stator slots. When current flows through the stator winding, it produces a uniform field flux.

Rotor:

There are mainly two types of rotor used in **construction of alternator**,

1. Salient pole type.
2. Cylindrical rotor type.

Construction of Salient Pole Rotor Machines

It consists of a stator and a rotor. The stator core is constructed with thin silicon lamination and insulated by a surface coating, to minimize the eddy current and hysteresis losses. The Stator has axial slots inside, in which three phase stator winding is placed.

The stator is wound with a three phase winding for a specific number of poles equal to the rotor poles.

The rotor in synchronous motors is mostly of salient pole type. DC supply is given to the rotor winding via slip-rings. The direct current excites the rotor winding and creates electromagnetic poles. In some cases permanent magnets can also be used.

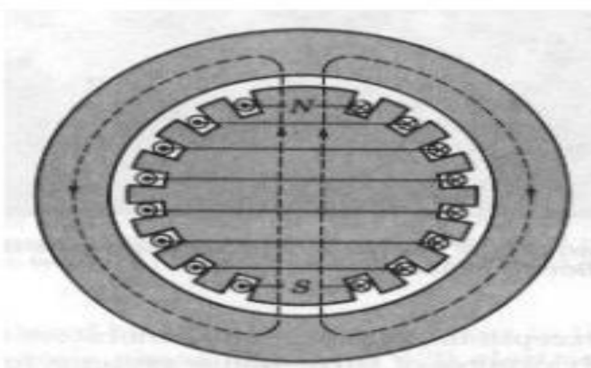
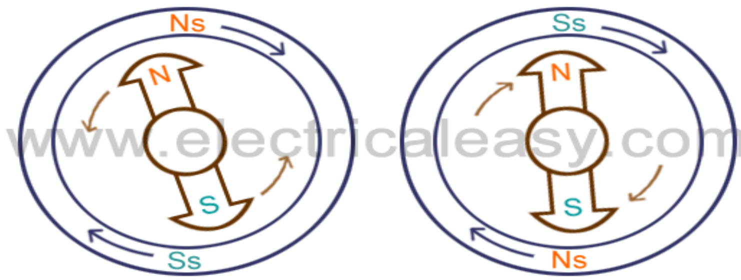


Fig. Salient pole synchronous machine

Working principle of salient pole synchronous machine

The stator is wound for the similar number of poles as that of rotor, and fed with three phase AC supply. The 3 phase AC supply produces rotating magnetic field in stator. The rotor winding is fed with DC supply which magnetizes the rotor. Consider a two pole **synchronous machine** as shown in figure below.



If the rotor position is such that, N pole of the rotor is near the N pole of the stator (as shown in first schematic of above figure), then the poles of the stator and rotor will repel each other, and the torque produced will be anticlockwise.

The stator poles are rotating with synchronous speed, and they rotate around very fast and interchange their position. But at this very soon, rotor can not rotate with the same angle (due to inertia), and the next position will be likely the second schematic in above figure. In this case, poles of the stator will attract the poles of rotor, and the torque produced will be clockwise.

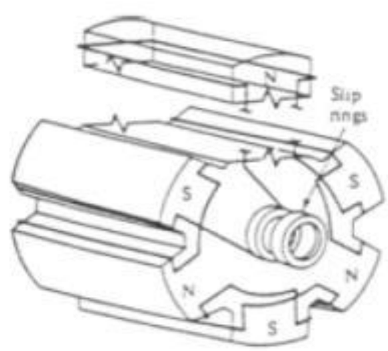


Fig. Salient pole rotor

Hence, the rotor will undergo to a rapidly reversing torque, and the motor will not start.

But, if the rotor is rotated up to the synchronous speed of the stator by means of an external force (in the direction of revolving field of the stator), and the rotor field is excited near the synchronous speed, the poles of stator will keep attracting the opposite poles of the rotor (as the rotor is also, now, rotating with it and the position of the poles will be similar throughout the cycle). Now, the rotor will undergo unidirectional torque. The opposite poles of the stator and rotor will get locked with each other, and the rotor will rotate at the synchronous speed.

The salient features of pole field structure has the following special feature-

1. They have a large horizontal diameter compared to a shorter axial length.
2. The pole shoes cover only about $^{2}/_{3}$rd of pole pitch.
3. Poles are laminated to reduce eddy current loss.
4. The salient pole type motor is generally used for low speed operations of around 100 to 400 rpm, and they are used in power stations with hydraulic turbines or diesel engines.

Construction of round (or) cylindrical rotor synchronous machine

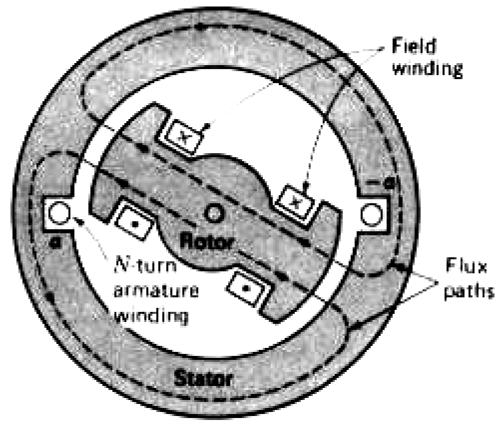


Fig. Round (or) cylindrical rotor

The cylindrical rotor is generally used for very high speed operation and are employed in steam turbine driven alternators like turbo generators. The cylindrical rotor type machine has uniform length in all directions, giving a cylindrical shape to the rotor thus providing uniform flux cutting in all directions. The rotor in this case consists of a smooth solid steel cylinder, having a number of slots along its outer periphery for hosing the field coils.

The cylindrical rotor alternators are generally designed for 2-pole type giving very high speed of

$N_s = (120 \times f)/P = (120 \times 50) / 2 = 3000$ rpm. Or 4-pole type running at a speed of $N_s = (120 \times f)/P = (120 \times 50) / 4 = 1500$ rpm. Where f is the frequency of 50 Hz.

The a cylindrical rotor synchronous generator does not have any projections coming out from the surface of the rotor, rather central polar area are provided with slots for housing the field windings as we can see from the diagram above. The field coils are so arranged around these poles that flux density is maximum on the polar central line and gradually falls away as we move out towards the periphery. The cylindrical rotor type machine gives better balance and quieter- operation along with lesser windage losses.

EMF Equation

Consider following

Φ= flux per pole in wb

P = Number of poles

Ns = Synchronous speed in rpm

f = frequency of induced emf in Hz

Z = total number of stator conductors

Z_{ph} = conductors per phase connected in series
T_{ph} = Number of turns per phase

Assuming concentrated winding, considering one conductor placed in a slot

According to Faraday's Law electromagnetic induction,

The average value of emf induced per conductor in one revolution $e_{avg} = d\Phi /dt$

e_{avg} = Change of Flux in one revolution/ Time taken for one revolution

Change of Flux in one revolution = p x Φ

Time taken for one revolution = 60/Ns seconds.

Hence $e_{avg} = (p \times \Phi) / (60/Ns) = p \times \Phi \times Ns / 60$

We know f = P Ns /120

hence PNs /60 = 2f Hence $e_{avg} = 2\Phi f$ volts

Hence average emf per turn = 2 x 2 Φ f volts = 4Φf volts

If there are Tph, number of turns per phase connected in series, then average emf induced in Tph turns is

$$\mathbf{E_{ph}\ avg = T_{ph} \times e_{avg} = 4 f \Phi T_{ph}\ volts}$$

Hence RMS value of emf induced $E = 1.11 \times E_{ph}$, avg

$= 1.11 \times 4 \Phi f T_{ph}$ volts

$= 4.44 f \Phi$ Tph volts

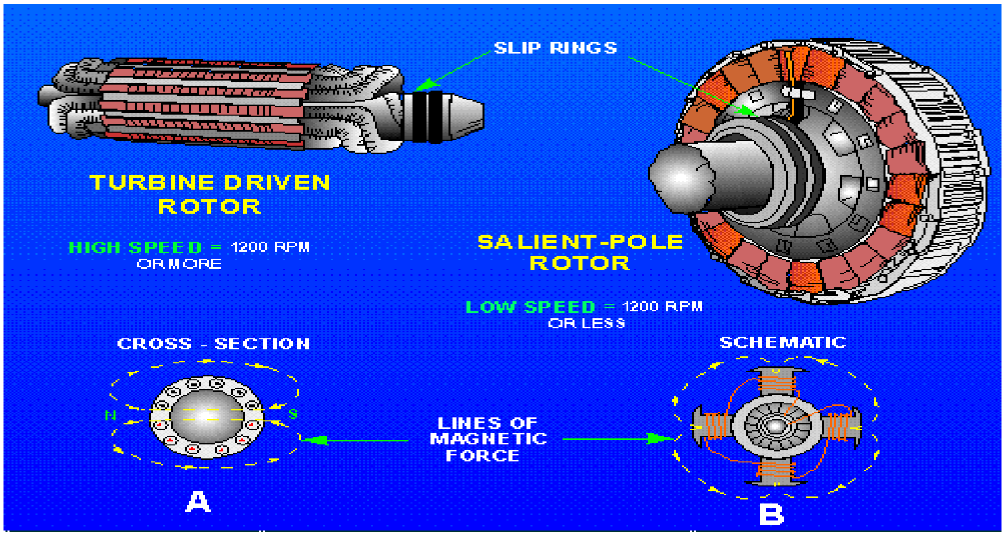
$$\mathbf{E_{ph}\ (avg) = 4.44 f \Phi T_{ph}\ volts}$$

This is the general emf equation for the machine having concentrated and full pitched winding. In practice, alternators will have short pitched winding and hence coil span will not be 180^o (degrees), but one or two slots short than the full pitch.

If we assume effect of K_d= Distribution factor and K_c or $K_P = \cos \alpha/2$

$$\mathbf{E_{ph},(avg) = 4.44 K_c K_d f \Phi T_{ph}\ volts}$$

This is the actual available voltage equation of an alternator per phase. If alternator or AC Generator is Star Connected as usually the case, then the Line Voltage is √3 times the phase voltage.


SLIP RINGS
TURBINE DRIVEN
ROTOR
HIGH SPEED = 1200 RPM
OR MORE
SALIENT-POLE
ROTOR
LOW SPEED = 1200 RPM
OR LESS
CROSS - SECTION
SCHEMATIC
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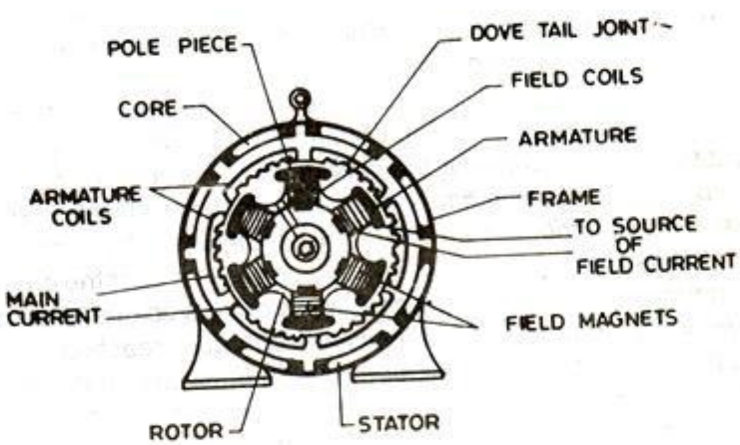
POLE PIECE
DOVE TAIL JOINT
FIELD COILS
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ARMATURE
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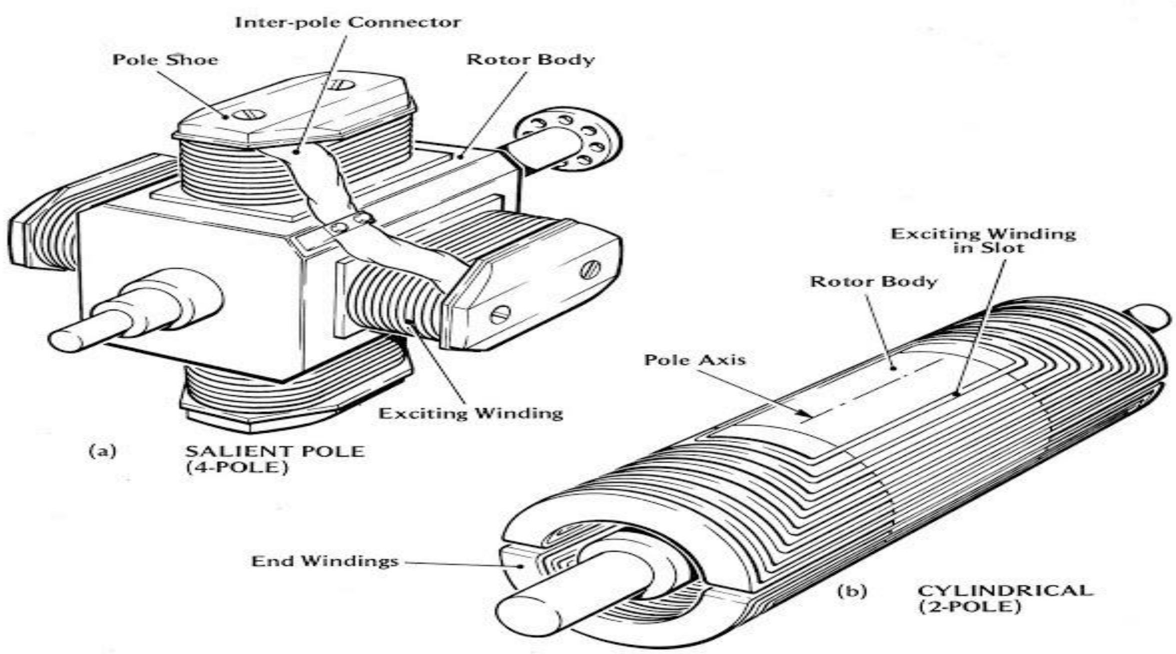
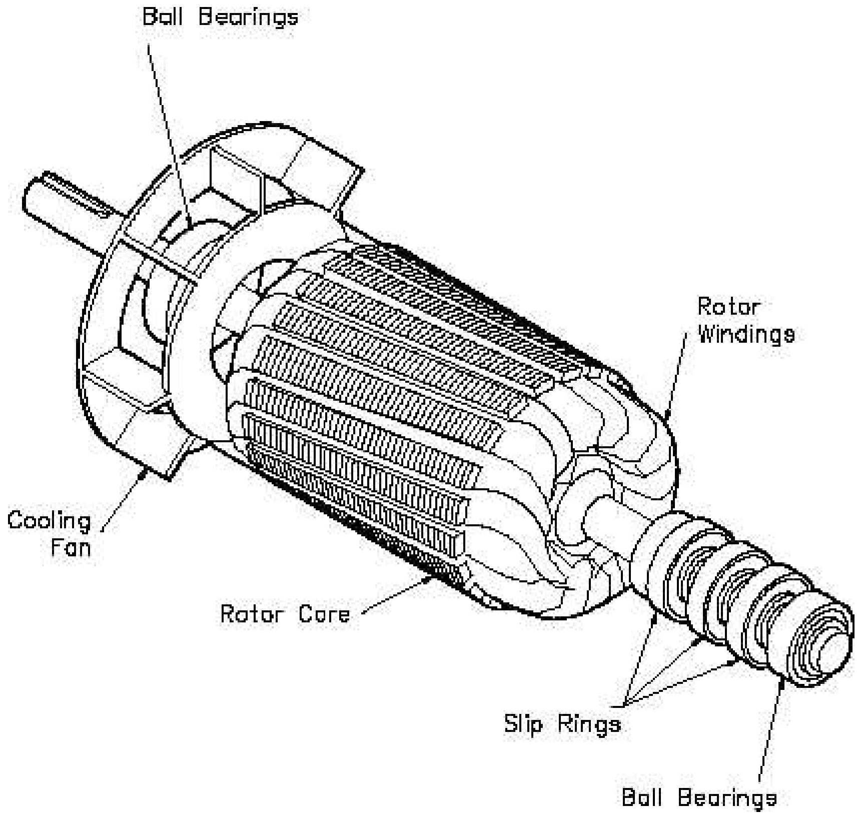
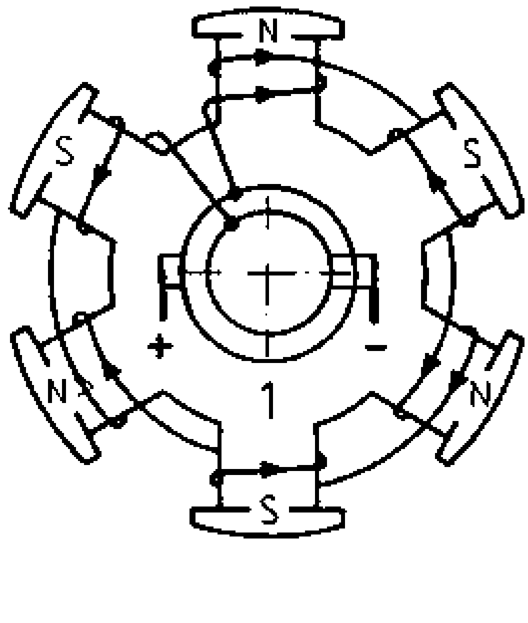
STATOR


Inter-pole Connector
Pole Shoe
Rotor Body
Exciting Winding
(a) SALIENT POLE
(4-POLE)
Exciting Winding
in Slot
Rotor Body
Pole Axis
End Windings
(b) CYLINDRICAL
(2-POLE)


Ball Bearings
Rotor
Windings
Cooling
Fan
Rotor Core
Slip Rings
Ball Bearings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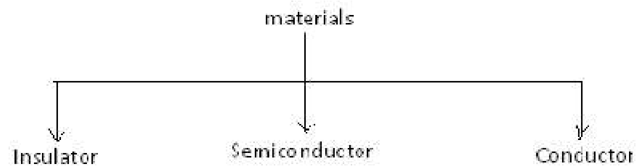
UNIT- I: - JUNCTION DIODE CHARACTERISTICS

1.0 INTRODUCTON

Based on the electrical conductivity all the materials in nature are classified as insulators, semiconductors, and conductors.



Insulator: An insulator is a material that offers a very low level (or negligible) of conductivity when voltage is applied. Eg: Paper, Mica, glass, quartz. Typical resistivity level of an insulator is of the order of 10^{10} to 10^{12} Ω-cm. The energy band structure of an insulator is shown in the fig.1.1. Band structure of a material defines the band of energy levels that an electron can occupy. Valance band is the range of electron energy where the electron remain bended too the atom and do not contribute to the electric current. Conduction bend is the range of electron energies higher than valance band where electrons are free to accelerate under the influence of external voltage source resulting in the flow of charge.

The energy band between the valance band and conduction band is called as forbidden band gap. It is the energy required by an electron to move from balance band to conduction band i.e. the energy required for a valance electron to become a free electron.

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

For an insulator, as shown in the fig.1.1 there is a large forbidden band gap of greater than 5Ev. Because of this large gap there a very few electrons in the CB and hence the conductivity of insulator is poor. Even an increase in temperature or applied electric field is insufficient to transfer electrons from VB to CB.

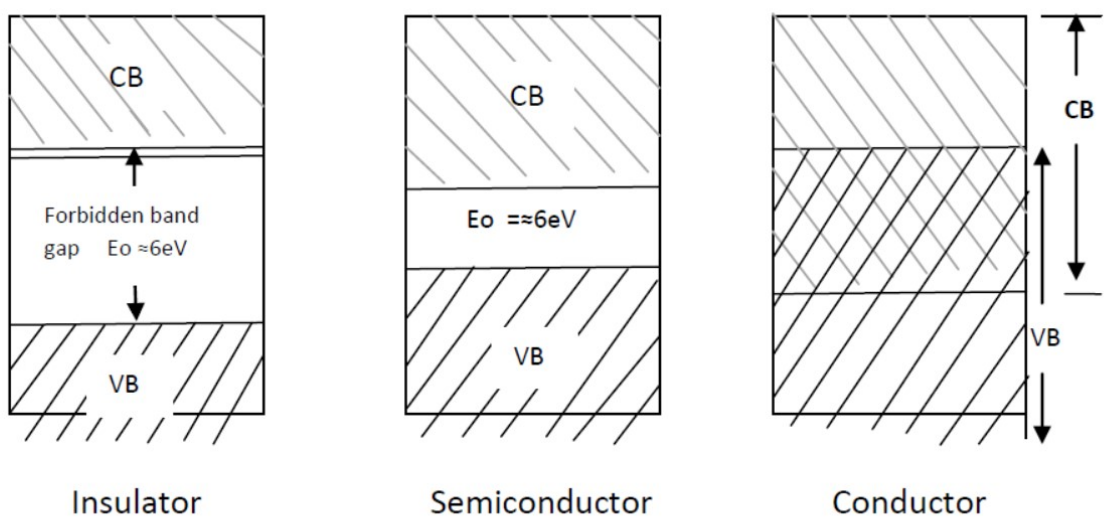


FiG:1.1 Energy band diagrams insulator, semiconductor and conductor

Conductors: A conductor is a material which supports a generous flow of charge when a voltage is applied across its terminals i.e. it has very high conductivity. E.g.: Copper, Aluminium, Silver, and Gold. The resistivity of a conductor is in the order of 10^{-4} and 10^{-6} Ω-cm. The Valance and conduction bands overlap (fig1.1) and there is no energy gap for the electrons to move from valance band to conduction band. This implies that there are free electrons in CB even at absolute zero temperature (0K).

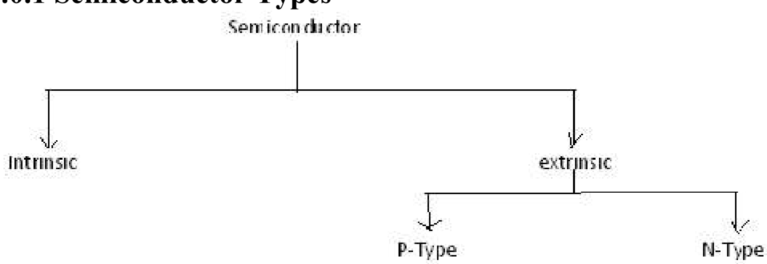
Therefore at room temperature when electric field is applied large current flows through the conductor.

Semiconductor: A semiconductor is a material that has its conductivity somewhere between the insulator and conductor. The resistivity level is in the range of 10 and 104 Ω-cm. Two of the most commonly used are Silicon (Si=14 atomic no.) and germanium (Ge=32 atomic no.). Both have 4 valance electrons. The forbidden band gap is in the order of 1eV. For e.g., the band gap energy for Si, Ge and GaAs is 1.21, 0.785 and 1.42 eV, respectively at absolute zero temperature (0K). At 0K and at low temperatures, the valance band electrons do not have sufficient energy to move from V to CB. Thus semiconductors act as insulators at 0K, as the temperature increases, a large number of valance electrons acquire sufficient energy to leave the VB, cross the forbidden band gap and reach CB. These are now free electrons as they can move freely under the influence of electric field. At room temperature there are sufficient electrons in the CB and hence the semiconductor is capable of conducting some current at room temperature. Inversely related to the conductivity of a material is its resistance to the flow of charge or current. Typical resistivity values for various materials' are given as follows.

Insulator	Semiconductor	Conductor
10^{-6} Ω-cm (Cu)	50Ω-cm (Ge)	10^{12} Ω-cm (mica)
	50×10^{3} Ω-cm (Si)	

Typical resistivity values

1.0.1 Semiconductor Types



A pure form of semiconductors is called as intrinsic semiconductor. Conduction in intrinsic sc is either due to thermal excitation or crystal defects. Si and Ge are the two most important semiconductors used. Other examples include Gallium arsenide GaAs, Indium Antimonide (InSb) etc.

Let us consider the structure of Si. A Si atomic no. is 14 and it has 4 valance electrons. These 4 electrons are shared by four neighbouring atoms in the crystal structure by means of covalent bond. Fig. 1.2a shows the crystal structure of Si at absolute zero temperature (0K). Hence a pure SC acts has poor conductivity (due to lack of free electrons) at low or absolute zero temperature.

At room temperature some of the covalent bonds break up to thermal energy as shown in fig 1.2b. The valance electrons that jump into conduction band are called as free electrons that are available for conduction.

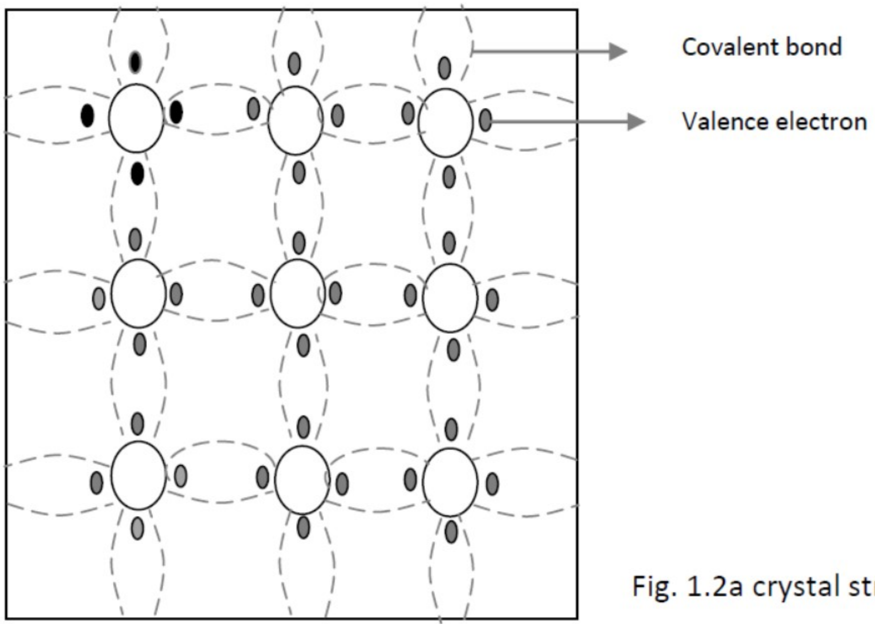


Fig. 1.2a crystal structure of Si at 0K

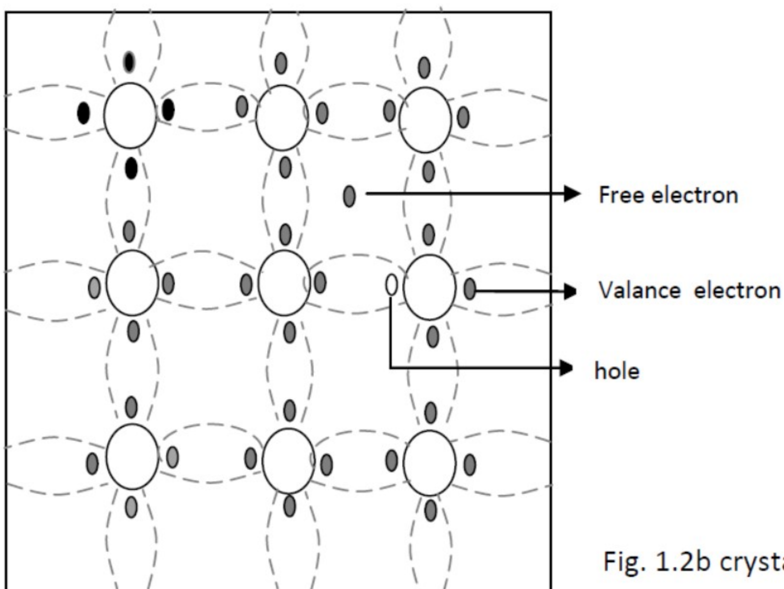
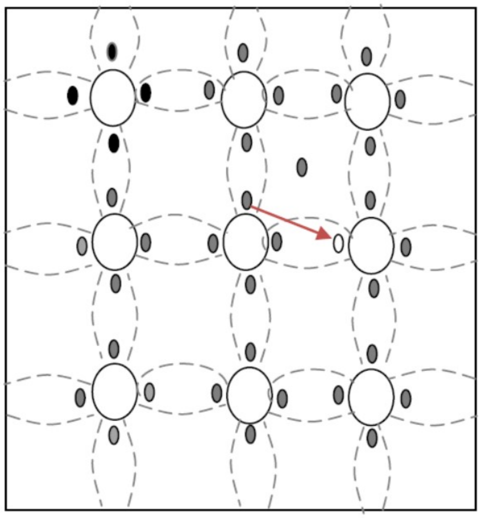


Fig. 1.2b crystal structure of Si at room temperature0K

The absence of electrons in covalent bond is represented by a small circle usually referred to as hole which is of positive charge. Even a hole serves as carrier of electricity in a manner similar to that of free electron.

The mechanism by which a hole contributes to conductivity is explained as follows:

When a bond is in complete so that a hole exists, it is relatively easy for a valance electron in the neighbouring atom to leave its covalent bond to fill this hole. An electron moving from a bond to fill a hole moves in a direction opposite to that of the electron. This hole, in its new position may now be filled by an electron from another covalent bond and the hole will correspondingly move one more step in the direction opposite to the motion of electron. Here we have a mechanism for conduction of electricity which does not involve free electrons. This phenomenon is illustrated in fig1.3



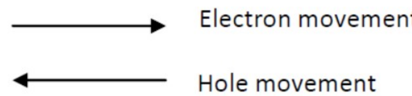


Fig. 1.3a

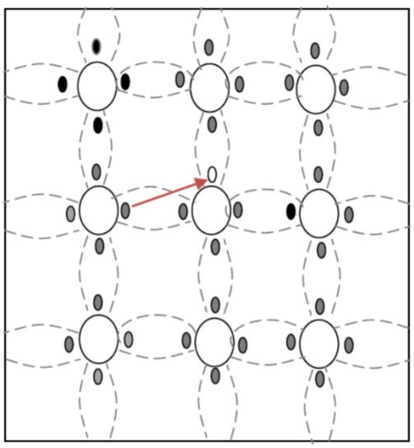


Fig. 1.3b

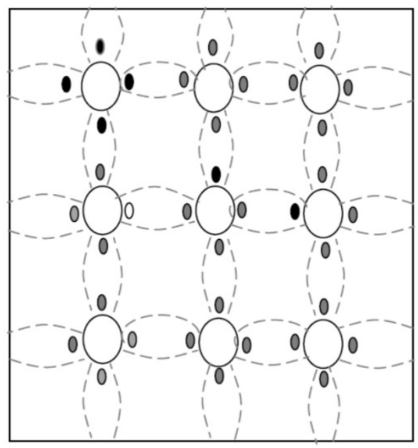


Fig. 1.3c

Fig 1.3a show that there is a hole at ion 6.Imagine that an electron from ion 5 moves into the hole at ion 6 so that the configuration of 1.3b results. If we compare both fig1.3a &fig 1.3b, it appears as if the hole has moved towards the left from ion6 to ion 5. Further if we compare fig 1.3b and fig 1.3c, the hole moves from ion5 to ion 4. This discussion indicates the motion of hole is in a direction opposite to that of motion of electron. Hence we consider holes as physical entities whose movement constitutes flow of current.

In a pure semiconductor, the number of holes is equal to the number of free electrons.

1.0.2 EXTRINSIC SEMICONDUCTOR

Intrinsic semiconductor has very limited applications as they conduct very small amounts of current at room temperature. The current conduction capability of intrinsic semiconductor can be increased significantly by adding a small amounts impurity to the intrinsic semiconductor. By adding impurities it becomes impure or extrinsic semiconductor. This process of adding impurities is called as doping. The amount of impurity added is 1 part in 10^6 atoms.

N type semiconductor: If the added impurity is a pentavalent atom then the resultant semiconductor is called N-type semiconductor. Examples of pentavalent impurities are Phosphorus, Arsenic, Bismuth, Antimony etc.

A pentavalent impurity has five valance electrons. Fig 1.4a shows the crystal structure of N-type semiconductor material where four out of five valance electrons of the impurity atom(antimony) forms covalent bond with the four intrinsic semiconductor atoms. The fifth electron is loosely bound to the impurity atom. This loosely bound electron can be easily

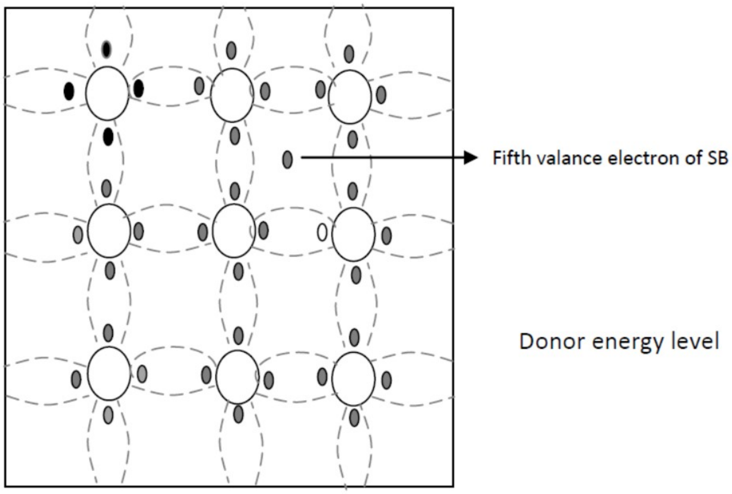


Fig. 1.4a crystal structure of N type SC

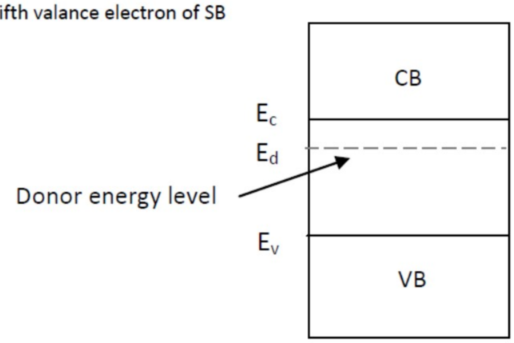


Fig. 1.4bEnergy band diagram of N type

Excited from the valance band to the conduction band by the application of electric field or increasing the thermal energy. The energy required to detach the fifth electron form the impurity atom is very small of the order of 0.01ev for Ge and 0.05 eV for Si.

The effect of doping creates a discrete energy level called donor energy level in the forbidden band gap with energy level Ed slightly less than the conduction band (fig 1.4b). The difference between the energy levels of the conducting band and the donor energy level is the energy required to free the fifth valance electron (0.01 eV for Ge and 0.05 eV for Si). At room temperature almost all the fifth electrons from the donor impurity atom are raised to conduction band and hence the number of electrons in the conduction band increases significantly. Thus every antimony atom contributes to one conduction electron without creating a hole.

In the N-type sc the no. of electrons increases and the no. of holes decreases compared to those available in an intrinsic sc. The reason for decrease in the no. of holes is that the larger no. of electrons present increases the recombination of electrons with holes. Thus current in N type sc is dominated by electrons which are referred to as majority carriers. Holes are the minority carriers in N type sc

P type semiconductor: If the added impurity is a trivalent atom then the resultant semiconductor is called P-type semiconductor. Examples of trivalent impurities are Boron, Gallium, indium etc. The crystal structure of p type sc is shown in the fig1.5a. The three valance electrons of the impurity (boon) forms three covalent bonds with the neighbouring atoms and a vacancy exists in the fourth bond giving rise to the holes. The hole is ready to accept an electron from the neighbouring atoms. Each trivalent atom contributes to one hole generation and thus introduces a large no. of holes in the valance band. At the same time the no. electrons are decreased compared to those available in intrinsic sc because of increased recombination due to creation of additional holes.

Thus in P type sc, holes are majority carriers and electrons are minority carriers. Since each trivalent impurity atoms are capable accepting an electron, these are called as acceptor atoms. The following fig 1.5b shows the pictorial representation of P type sc

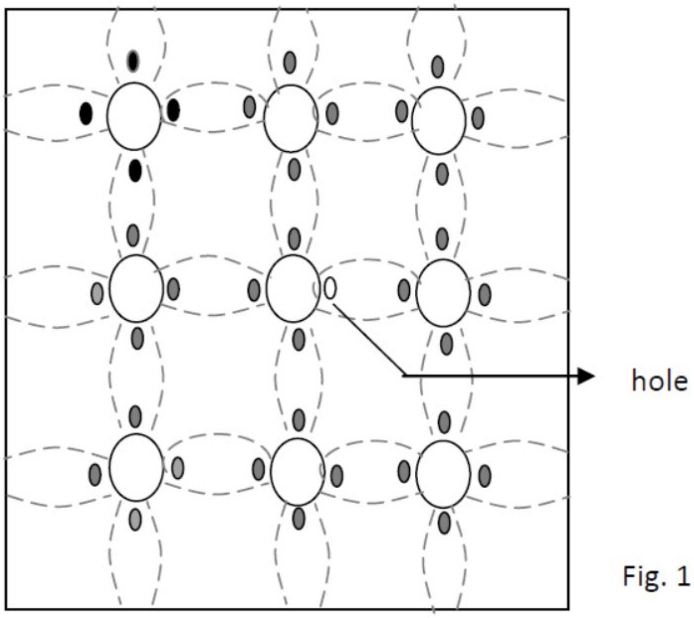


Fig. 1.5a crystal structure of P type sc

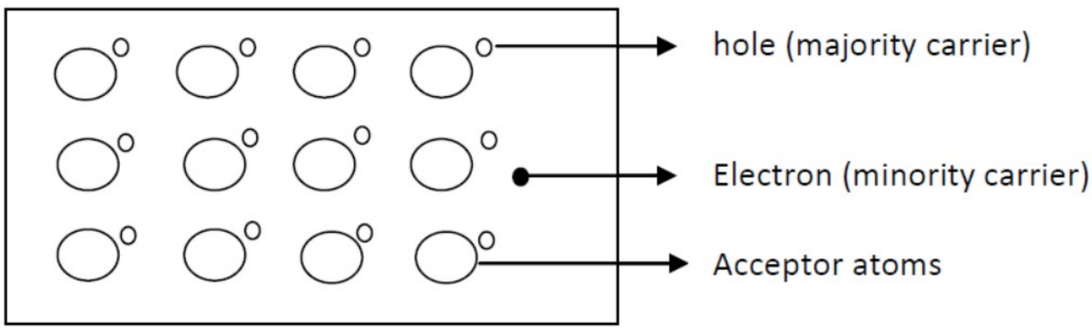


Fig. 1.5b crystal structure of P type sc

- The conductivity of N type sc is greater than that of P type sc as the mobility of electron is greater than that of hole.
- For the same level of doping in N type sc and P type sc, the conductivity of an N type sc is around twice that of a P type sc

1.0.3 CONDUCTIVITY OF SEMICONDUCTOR

In a pure sc, the no. of holes is equal to the no. of electrons. Thermal agitation continue to produce new electron- hole pairs and the electron hole pairs disappear because of recombination. With each electron hole pair created, two charge carrying particles are formed. One negative which is a free electron with mobility μ_n. The other is a positive i.e., hole with mobility μ_p. The electrons and hole move in opposite direction in an electric field E, but since they are of opposite sign, the current due to each is in the same direction. Hence the total current density J within the intrinsic sc is given by

$$\begin{aligned} J &= J_n + J_p \\ &= q\, n\, \mu_n E + q\, p\, \mu_p E \\ &= (n\, \mu_n + p\, \mu_p)\, qE \\ &= \sigma E \end{aligned}$$

Where n=no. of electrons / unit volume i.e., concentration of free electrons

P= no. of holes / unit volume i.e., concentration of holes

E=applied electric field strength, V/m

q= charge of electron or hole I n Coulombs

Hence, σ is the conductivity of sc which is equal to ($n\ \mu_n + p\ \mu_p$) q. The resistivity of sc is reciprocal of conductivity.

$\rho = 1/\sigma$

It is evident from the above equation that current density with in a sc is directly proportional to applied electric field E.

For pure sc, $n=p=n_i$ where n_i = intrinsic concentration. The value of n_i is given by

$$n_i^2 = AT^3 e^{(-\frac{\mathrm{EG_0}}{\mathrm{KT}})}$$

Therefore, $J= n_i\ (\mu n + \mu_p)\ q\ E$

Hence conductivity in intrinsic sc is $\sigma_i= n_i\ (\mu n + \mu_p)\ q$

Intrinsic conductivity increases at the rate of 5% per o C for Ge and 7% per o C for Si.

Conductivity in extrinsic sc (N Type and P Type):

The conductivity of intrinsic sc is given by $\sigma_i= n_i\ (\mu n + \mu_p)\ q = (n\ \mu_n + p\ \mu_p)\ q$

For N type, n>>p; Therefore $\sigma= q\ n\ \mu_n$

For P type, p>>n; Therefore $\sigma= q\ p\ \mu_p$

1.0.4 CHARGE DENSITIES IN P TYPE AND N TYPE SEMICONDUCTOR:

Mass Action Law:

Under thermal equilibrium for any semiconductor, the product of the no. of holes and the concentration of electrons is constant and is independent of amount of donor and acceptor impurity doping.

$n.p= n_i^2$

Where n= electron concentration

p = hole concentration

n_i^2= intrinsic concentration

Hence in N-type sc, as the no. of electrons increases the no. of holes decreases. Similarly in P-type as the no. of holes increases the no. of electrons decreases. Thus the product is constant and is equal to n_i^2 in case of intrinsic as well as extrinsic sc.

The law of mass action has given the relationship between free electrons concentration and hole concentration. These concentrations are further related by the law of electrical neutrality as explained below.

Law of electrical neutrality:

Sc materials are electrically neutral. According to the law of electrical neutrality, in an electrically neutral material, the magnitude of positive charge concentration is equal to that of negative charge concentration. Let us consider a sc that has N_D donor atoms per cubic centimetre and N_A acceptor atoms per cubic centimetre i.e., the concentration of donor and acceptor atoms are N_D and N_A respectively. Therefore N_D positively charged ions per cubic centimetre are contributed by donor atoms and N_A negatively charged ions per cubic centimetre are contributed by the acceptor atoms. Let n, p is concentration of free electrons and holes respectively. Then according to the law of neutrality

$N_D + p = N_A + n$ eq. 1.1

For N type sc, N_A =0 and n>>p. Therefore $N_D \approx n$ eq. 1.2

Hence for N type sc the free electron concentration is approximately equal to the concentration of donor atoms. In later applications since some confusion may arise as to which type of sc is under consideration a given moment, the subscript n or p is added for N-type or P-type respectively.

Hence eq1.2 becomes $N_D \approx n_n$

Therefore current density in N type sc is $J = N_D \mu_n q E$ and conductivity $\sigma = N_D \mu_n q$

For P type sc, $N_D = 0$ and p>>n. Therefore $N_A \approx p$ or $N_A \approx p_p$

Hence for P type sc the hole concentration is approximately equal to the concentration of acceptor atoms.

Therefore current density in N type sc is $J = N_A \mu_p q E$ and conductivity $\sigma = N_A \mu_p q$

Mass action law for N type, $n_n p_n = n_i^2$

$$p_n = n_i^2 / N_D \text{ since } (n_n \approx N_D)$$

Mass action law for P type, $n_p p_p = n_i^2$

$$n_p = n_i^2 / N_A \text{ since } (p_p \approx N_A)$$

1.1 QUANTITATIVE THEORY OF PN JUNCTION DIODE

1.1.1 PN JUNCTION WITH NO APPLIED VOLTAGE OR OPEN CIRCUIT CONDITION:

In a piece of sc, if one half is doped by P-type impurity and the other half is doped by N-type impurity, a PN junction is formed. The plane dividing the two halves or zones is called PN junction. As shown in the fig the N-type material has high concentration of free electrons, while P-type material has high concentration of holes. Therefore at the junction there is a tendency of free electrons to diffuse over to the P side and the holes to the N side. This process is called diffusion. As the free electrons move across the junction from N-type to P-type, the donor atoms become positively charged. Hence a positive charge is built on the N-side of the junction. The free electrons that cross the junction uncover the negative acceptor ions by filing the holes. Therefore a negative charge is developed on the P side of the junction. This net negative charge on the P side prevents further diffusion of electrons into the P side. Similarly the net positive charge on the N side repels the hole crossing from P side to N side. Thus a barrier sis set up near the junction which prevents the further movement of charge carriers i.e. electrons and holes. As a consequence of induced electric field across the depletion layer, an electrostatic potential difference is established between P and N regions, which are called the potential barrier, junction barrier, diffusion potential or contact potential, Vo. The magnitude of the contact potential V_o varies with doping levels and temperature V_o is 0.3V for Ge and 0.72 V for Si.

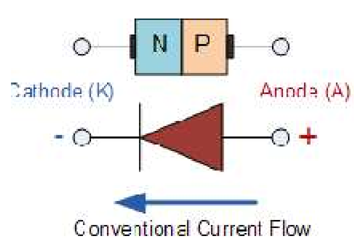


Fig 1.6: Symbol of PN Junction Diode

The electrostatic field across the junction caused by the positively charged N-Type region tends to drive the holes away from the junction and negatively charged P-type regions tend to drive the electrons away from the junction. The majority holes diffusing out of the P region leave behind negatively charged acceptor atoms bound to the lattice, thus exposing a negatives pace charge in a previously neutral region. Similarly electrons diffusing from the N region expose positively ionized donor atoms and a double space charge builds up at the junction as shown in the fig. 1.7a

It is noticed that the space charge layers are of opposite sign to the majority carriers diffusing into them, which tends to reduce the diffusion rate. Thus the double space of the layer causes an electric field to be set up across the junction directed from N to P regions, which is in such a direction to inhibit the diffusion of majority electrons and holes as illustrated in fig 1.7b. The shape of the charge density, ρ, depends upon how diode id doped. Thus the junction region is depleted of mobile charge carriers. Hence it is called depletion layer, space region, and transition region. The depletion region is of the order of 0.5μm thick. There are no mobile carriers in this narrow depletion region. Hence no current flows across the junction and the system is in equilibrium. To the left of this depletion layer, the carrier concentration is p= N_A and to its right it is n= N_D.

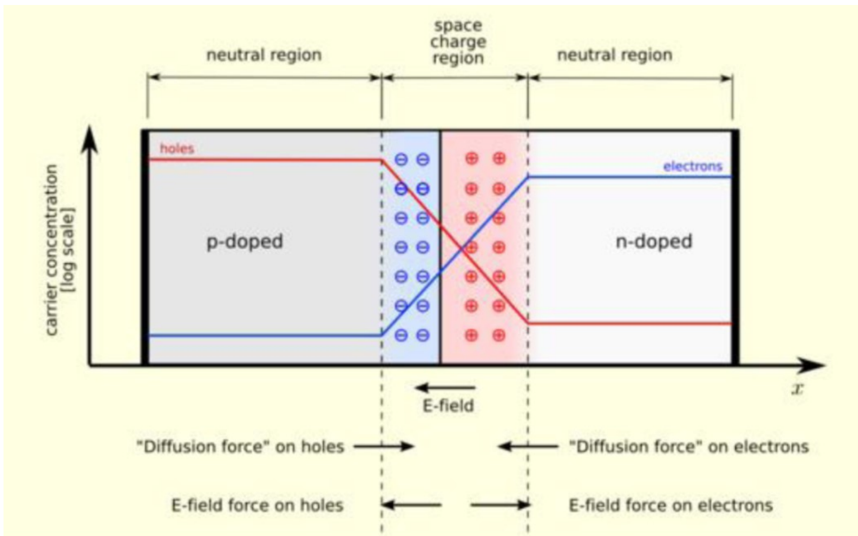


Fig 1.7a

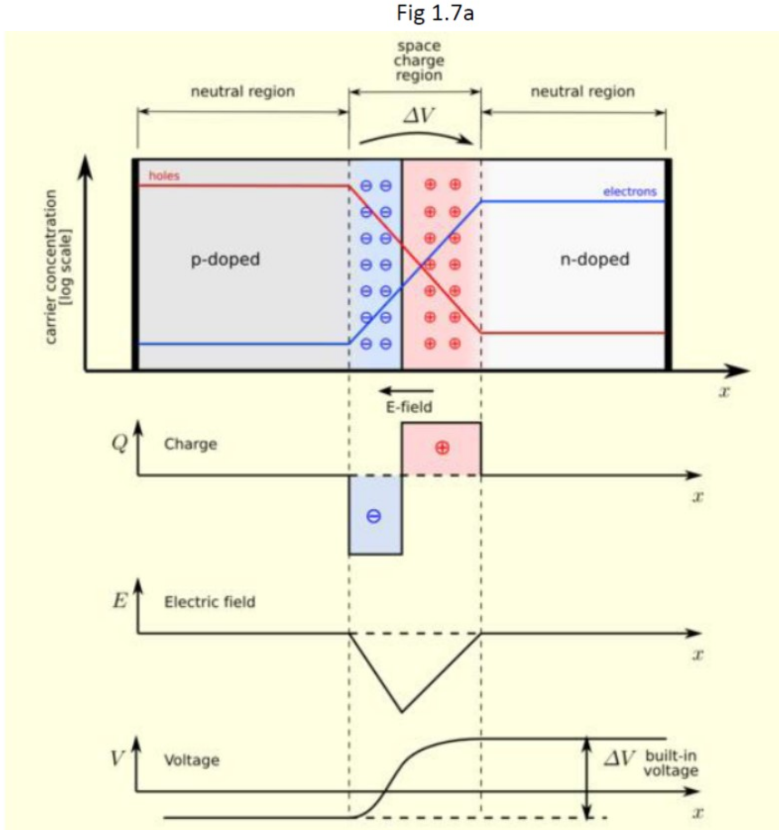


Fig 1.7b

1.1.2 FORWARD BIASED JUNCTION DIODE

When a diode is connected in a **Forward Bias** condition, a negative voltage is applied to the N-type material and a positive voltage is applied to the P-type material. If this external voltage becomes greater than the value of the potential barrier, approx. 0.7 volts for silicon and 0.3 volts for germanium, the potential barriers opposition will be overcome and current will start to flow. This is because the negative voltage pushes or repels electrons towards the junction giving them the energy to cross over and combine with the holes being pushed in the opposite direction towards the junction by the positive voltage. This results in a characteristics curve of zero current flowing up to this voltage point, called the "knee" on the static curves and then a high current flow through the diode with little increase in the external voltage as shown below.

Forward Characteristics Curve for a Junction Diode

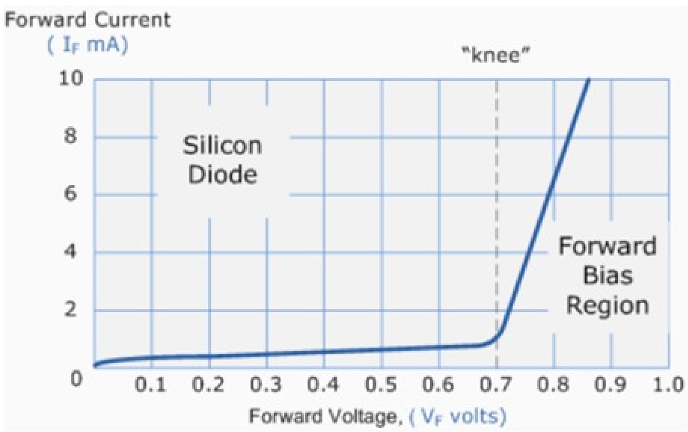


Fig 1.8a: Diode Forward Characteristics

The application of a forward biasing voltage on the junction diode results in the depletion layer becoming very thin and narrow which represents a low impedance path through the junction thereby allowing high currents to flow. The point at which this sudden increase in current takes place is represented on the static I-V characteristics curve above as the "knee" point.

Forward Biased Junction Diode showing a Reduction in the Depletion Layer

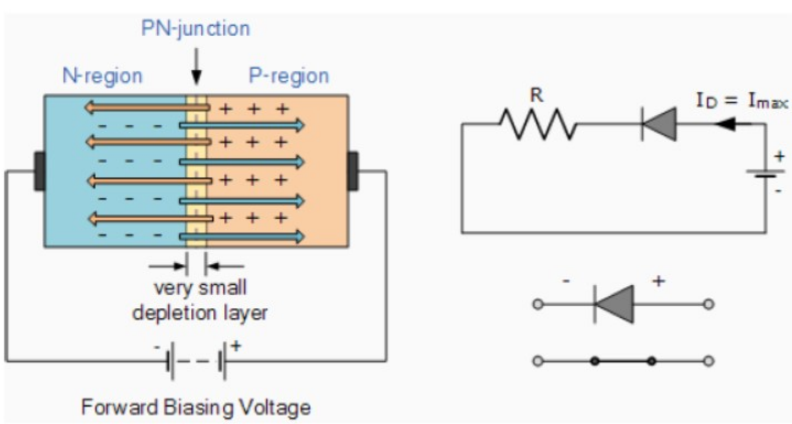


Fig 1.8b: Diode Forward Bias

This condition represents the low resistance path through the PN junction allowing very large currents to flow through the diode with only a small increase in bias voltage. The actual potential difference across the junction or diode is kept constant by the action of the depletion layer at approximately 0.3v for germanium and approximately 0.7v for silicon junction diodes. Since the diode can conduct "infinite" current above this knee point as it effectively becomes a short circuit, therefore resistors are used in series with the diode to limit its current flow. Exceeding its maximum forward current specification causes the device to dissipate more power in the form of heat than it was designed for resulting in a very quick failure of the device.

1.1.2 PN JUNCTION UNDER REVERSE BIAS CONDITION:

Reverse Biased Junction Diode

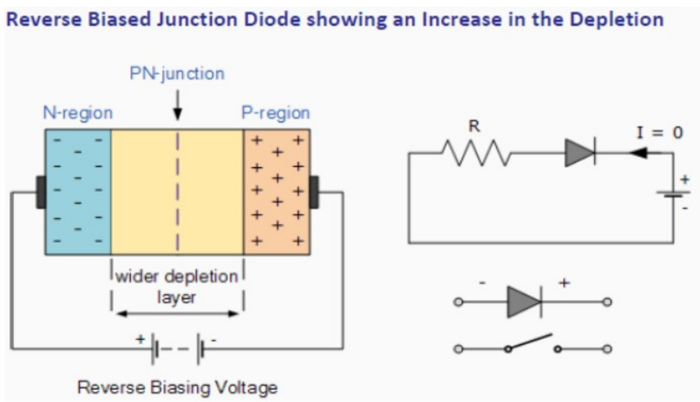


Fig 1.9a: Diode Reverse Bias

This condition represents a high resistance value to the PN junction and practically zero current flows through the junction diode with an increase in bias voltage. However, a very small **leakage current** does flow through the junction which can be measured in microamperes, (μA). One final point, if the reverse bias voltage Vr applied to the diode is increased to a sufficiently high enough value, it will cause the PN junction to overheat and fail due to the avalanche effect around the junction. This may cause the diode to become shorted and will result in the flow of maximum circuit current, and this shown as a step downward slope in the reverse static characteristics curve below.

Reverse Characteristics Curve for a Junction Diode

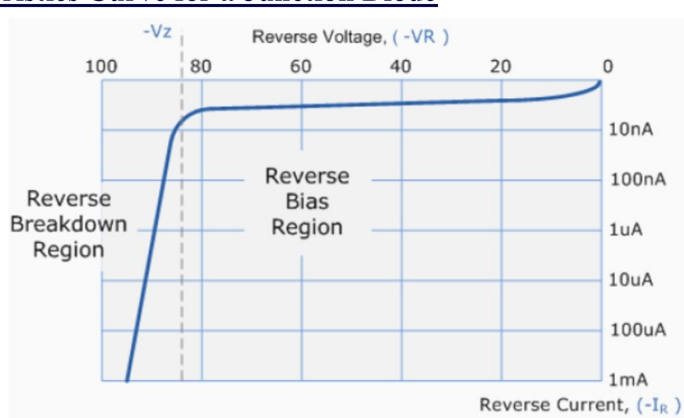


Fig 1.9b: Diode Reverse Characteristics

Sometimes this avalanche effect has practical applications in voltage stabilizing circuits where a series limiting resistor is used with the diode to limit this reverse breakdown current to a preset maximum value thereby producing a fixed voltage output across the diode. These types of diodes are commonly known as **Zener Diodes.**

1.2 VI CHARACTERISTICS AND THEIR TEMPERATURE DEPENDENCE

Diode terminal characteristics equation for diode junction current:

$$I_D = I_0\left(e^{V/nV_T} - 1\right)$$

Where VT = KT/q;

VD - diode terminal voltage, Volts

Io - temperature-dependent saturation current, µA

T - Absolute temperature of p-n junction, K

K - Boltzmann's constant 1.38x 10 -23J/K)

q - Electron charge $1.6\text{x}10^{-19}$ C

n - Empirical constant, 1 for Ge and 2 for Si

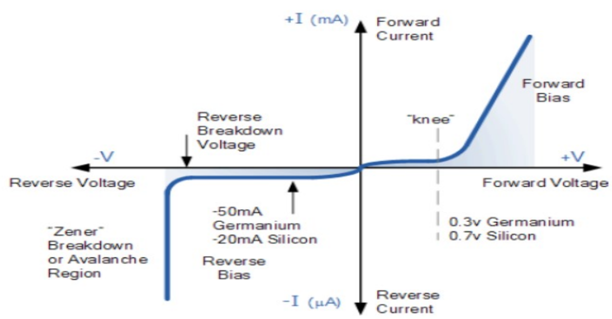


Fig 1.10: Diode Characteristics

Temperature Effects on Diode

Temperature can have a marked effect on the characteristics of a silicon semiconductor diode as shown in Fig 1.11 It has been found experimentally that the reverse saturation current Io will just about double in magnitude for every 10°C increase in temperature.

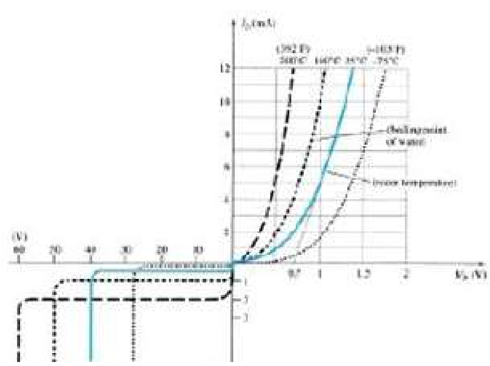


Fig 1.11 Variation in Diode Characteristics with temperature change

It is not uncommon for a germanium diode with an Io in the order of 1 or 2 A at 25°C to have a leakage current of 100 A - 0.1 mA at a temperature of 100°C. Typical values of Io for silicon are much lower than that of germanium for similar power and current levels. The result is that even at high temperatures the levels of I_o for silicon diodes do not reach the same high levels obtained. For germanium—a very important reason that silicon devices enjoy a significantly higher level of development and utilization in design. Fundamentally, the open-circuit equivalent in the reverse bias region is better realized at any temperature with silicon than with germanium. The increasing levels of I_o with temperature account for the lower levels of threshold voltage, as shown in Fig. 1.11. Simply increase the level of I_o in and not rise in diode current. Of course, the level of T_K also will be increase, but the increasing level of Io will overpower the smaller percent change in T_K. As the temperature increases the forward characteristics are actually becoming more "ideal".

1.3 IDEAL VERSUS PRACTICAL RESISTANCE LEVELS

DC or Static Resistance

The application of a dc voltage to a circuit containing a semiconductor diode will result in an operating point on the characteristic curve that will not change with time. The resistance of the diode at the operating point can be found simply by finding the corresponding levels of V_D and I_D as shown in Fig. 1.12 and applying the following Equation:

$$R_d=V_D/I_D$$

The dc resistance levels at the knee and below will be greater than the resistance levels obtained for the vertical rise section of the characteristics. The resistance levels in the reverse-bias region will naturally be quite high. Since ohmmeters typically employ a relatively constant-current source, the resistance determined will be at a preset current level (typically, a few mill amperes).

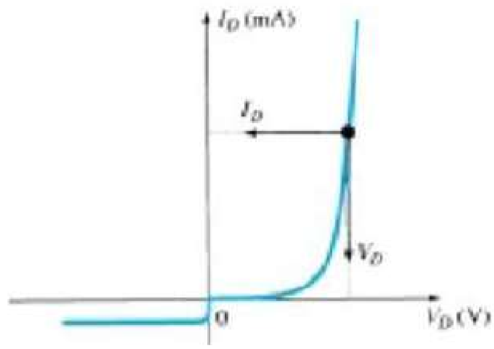


Fig 1.12 Determining the dc resistance of a diode at a particular operating point.

AC or Dynamic Resistance

It is obvious from Eq. 1.3 that the dc resistance of a diode is independent of the shape of the characteristic in the region surrounding the point of interest. If a sinusoidal rather than dc input is applied, the situation will change completely. The varying input will move the instantaneous operating point up and down a region of the characteristics and thus defines a specific change in current and voltage as shown in Fig. 1.13. With no applied varying signal, the point of operation would be the Q point appearing on Fig. 1.13 determined by the applied dc levels. The designation Q-point is derived from the word quiescent, which means "still or unvarying." A straight-line drawn tangent to the curve through the Q-point as shown in Fig. 1.13 will define a particular change in voltage and current that can be used to determine the ac or dynamic resistance for this region of the diode characteristics. In equation form,

$$r_d=\Delta V_D/\Delta I_D$$

Where Δ signifies a finite change in the quantity

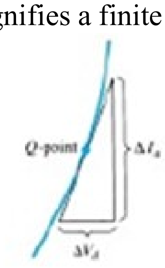


Fig 1.13: Determining the ac resistance of a diode at a particular operating point.

1.4 DIODE EQUIVALENT CIRCUITS

An equivalent circuit is a combination of elements properly chosen to best represent the actual terminal characteristics of a device, system, or such in a particular operating region. In other words, once the equivalent circuit is defined, the device symbol can be removed from a schematic and the equivalent circuit inserted in its place without severely affecting the actual behaviour of the system. The result is often a network that can be solved using traditional circuit analysis techniques.

Piecewise-Linear Equivalent Circuit

One technique for obtaining an equivalent circuit for a diode is to approximate the characteristics of the device by straight-line segments, as shown in Fig. 1.31. The resulting equivalent circuit is naturally called the piecewise-linear equivalent circuit. It should be obvious from Fig. 1.31 that the straight-line segments do not result in an exact duplication of the actual characteristics, especially in the knee region. However, the resulting segments are sufficiently close to the actual curve to establish an equivalent circuit that will provide an excellent first approximation to the actual behaviour of the device. The ideal diode is included to establish that there is only one direction of conduction through the device, and a reverse-bias condition will result in the open- circuit state for the device. Since a silicon semiconductor, diode does not reach the conduction state until V_D reaches 0.7 V with a forward bias (as shown in Fig. 1.14a), a battery V_T opposing the conduction direction must appear in the equivalent circuit as shown in Fig. 1.14b. The battery simply specifies that the voltage across the device must be greater than the threshold battery voltage before conduction through the device in the direction dictated by the ideal diode can be established. When conduction is established, the resistance of the diode will be the specified value of rav.

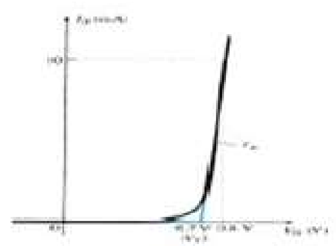


Fig: 1.14aDiode piecewise-linear model characteristics

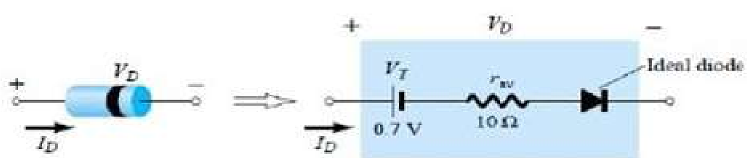


Fig: 1.14b Diode piecewise-linear model equivalent circuit

The approximate level of r_{av} can usually be determined from a specified operating point on the specification sheet. For instance, for a silicon semiconductor diode, if I_F =10 mA (a forward conduction current for the diode) at V_D=0.8 V, we know for silicon that a shift of 0.7 V is required before the characteristics rise.

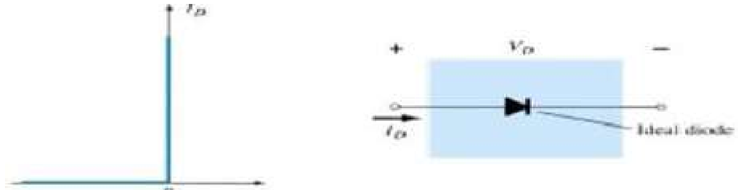


Fig 1.15 Ideal Diode and its characteristics

Diode capacitances: The diode exhibits two types of capacitances transition capacitance and diffusion capacitance.

- Transition capacitance: The capacitance which appears between positive ion layer in n-region and negative ion layer in p-region.
- Diffusion capacitance: This capacitance originates due to diffusion of charge carriers in the opposite regions.

The transition capacitance is very small as compared to the diffusion capacitance.

$$\boxed{C_T = \epsilon A/W}$$

where C_T - transition capacitance
A - diode cross sectional area
W - depletion region width

In forward bias, the diffusion capacitance is the dominant and is given by:

$$\boxed{C_D = dQ/dV = \tau^*dI/dV = \tau^*g = \tau/r \text{ (general)}}$$

where CD - diffusion capacitance
dQ - change in charge stored in depletion region
dV - change in applied voltage- time interval for change in voltage
g - Diode conductance
r - diode resistance

The diffusion capacitance at low frequencies is given by the formula:

$$\boxed{C_D = \tau^*g/2 \text{ (low frequency)}}$$

The diffusion capacitance at high frequencies is inversely proportional to the frequency and is given by the formula:

$$\boxed{C_D = g(\tau/2\omega)^{½}}$$

1.6 BREAK DOWN MECHANISMS

When an ordinary **P-N junction diode** is reverse biased, normally only very small reverse saturation current flows. This current is due to movement of minority carriers. It is almost independent of the voltage applied. However, if the reverse bias is increased, a point is reached when the junction breaks down and the reverse current increases abruptly. This current could be large enough to destroy the junction. If the reverse current is limited by means of a suitable series resistor, the power dissipation at the junction will not be excessive, and the device may be operated continuously in its breakdown region to its normal (reverse saturation) level. It is found that for a suitably designed diode, the breakdown voltage is very stable over a wide range of reverse currents. This quality gives the breakdown diode many useful applications as a voltage reference source.

The critical value of the voltage, at which the breakdown of a P-N junction diode occurs, is called the *breakdown voltage.* The breakdown voltage depends on the width of the depletion region, which, in turn, depends on the doping level. The junction offers almost zero resistance at the breakdown point. There are two mechanisms by which breakdown can occur at a reverse biased P-N junction:

1. ***Avalanche breakdown*** **and**
2. ***Zener breakdown.***

Avalanche breakdown: The minority carriers, under reverse biased conditions, flowing through the junction acquire a kinetic energy which increases with the increase in reverse voltage. At a sufficiently high reverse voltage (say 5 V or more), the kinetic energy of minority carriers becomes so large that they knock out electrons from the covalent bonds of the semiconductor material. As a result of collision, the liberated electrons in turn liberate more electrons and the current becomes very large leading to the breakdown of the crystal structure itself. This phenomenon is called the avalanche breakdown. The breakdown region is the knee of the characteristic curve. Now the current is not controlled by the junction voltage but rather by the external circuit.

Zener breakdown: Under a very high reverse voltage, the depletion region expands and the potential barrier increases leading to a very high electric field across the junction. The electric field will break some of the covalent bonds of the semiconductor atoms leading to a large number of free minority carriers, which suddenly increase the reverse current. This is called the Zener effect. The breakdown occurs at a particular and constant value of reverse voltage called the breakdown voltage; it is found that Zener breakdown occurs at electric field intensity of about 3 x 107 V/m.

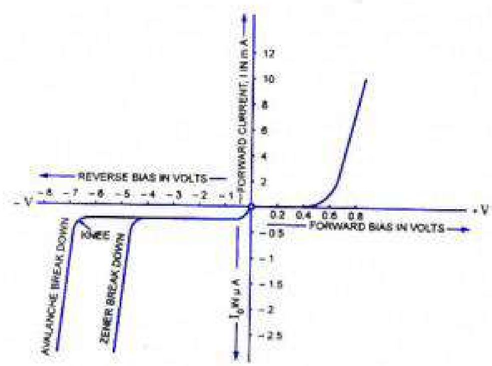


Fig 1.18: Diode characteristics with breakdown

Either of the two (Zener breakdown or avalanche breakdown) may occur independently, or both of these may occur simultaneously. Diode junctions that breakdown below 5 V are caused by Zener effect. Junctions that experience breakdown above 5 V are caused by avalanche effect. Junctions that breakdown around 5 V are usually caused by combination of two effects. The Zener breakdown occurs in heavily doped junctions (P-type semiconductor moderately doped and N-type heavily doped), which produce narrow depletion layers. The avalanche breakdown occurs in lightly doped junctions, which produce wide depletion layers. With the increase in junction temperature Zener breakdown voltage is reduced while the avalanche breakdown voltage increases. The Zener diodes have a negative temperature coefficient while avalanche diodes have a positive temperature coefficient. Diodes that have breakdown voltages around 5 V have temperature coefficient zero. The breakdown phenomenon is reversible and harmless so long as the safe operating temperature is maintained.

1.7 ZENER DIODES

The **Zener diode** is like a general-purpose signal diode consisting of a silicon PN junction. When biased in the forward direction it behaves just like a normal signal diode passing the rated current, but as soon as a reverse voltage applied across the Zener diode exceeds the rated voltage of the device, the diodes breakdown voltage V_B is reached at which point a process called *Avalanche Breakdown* occurs in the semiconductor depletion layer and a current starts to flow through the diode to limit this increase in voltage.

The current now flowing through the zener diode increases dramatically to the maximum circuit value (which is usually limited by a series resistor) and once achieved this reverse saturation current remains fairly constant over a wide range of applied voltages. This breakdown voltage point, V_B is called the "zener voltage" for zener diodes and can range from less than one volt to hundreds of volts.

The point at which the zener voltage triggers the current to flow through the diode can be very accurately controlled (to less than 1% tolerance) in the doping stage of the diodes semiconductor construction giving the diode a specific *zener breakdown voltage*, (V_z) for example, 4.3V or 7.5V. This zener breakdown voltage on the I-V curve is almost a vertical straight line.

Zener Diode I-V Characteristics

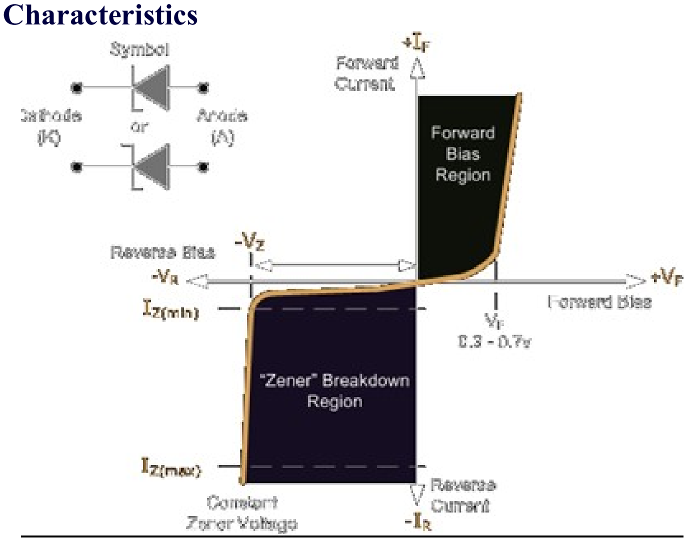


Fig 1.19 Zener diode characteristics

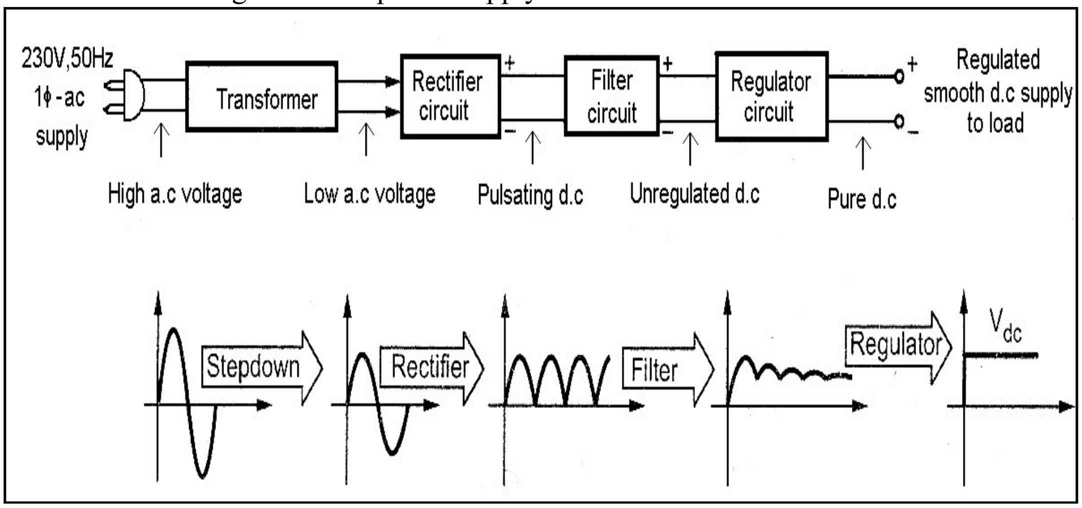
The **Zener Diode** is used in its "reverse bias" or reverse breakdown mode, i.e. the diodes anode connects to the negative supply. From the I-V characteristics curve above, we can see that the Zener diode has a region in its reverse bias characteristics of almost a constant negative voltage regardless of the value of the current flowing through the diode and remains nearly constant even with large changes in current as long as the Zener diodes current remains between the breakdown current $I_Z(min)$ and the maximum current rating $I_Z(max)$.

This ability to control itself can be used to great effect to regulate or stabilize a voltage source against supply or load variations. The fact that the voltage across the diode in the breakdown region is almost constant turns out to be an important application of the Zener diode as a voltage regulator. The function of a regulator is to provide a constant output voltage to a load connected in parallel with it in spite of the ripples in the supply voltage or the variation in the load current and the Zener diode will continue to regulate the voltage until the diodes current falls below the minimum $I_Z(min)$ value in the reverse breakdown region.

RECTIFIERS AND FILTERS

Block Diagram of D.C Power Supply

The block diagram of d.c power supply is shown in



It consists of a transformer, rectifier, filter and regulator circuits.

Transformer

The transformer step-up or step-down the input voltage into required voltage, and it also isolates the rectifier unit from power line and reduces the electrical shock.

Rectifier

A rectifier is a device which converts a.c voltage into pulsating d.c voltage using one or more PN-junction diodes.

*Note: The rectifier is the heart of d.c power supply.

Filter

The output of rectifier is not pure d.c. It contains both d.c components and a.c components (a part of a.c).

A filter is a circuit, which removes the ripples (or unwanted a.c components) present in the rectifier output.

Regulator

It is a circuit, which maintains output voltage constant even if the input voltage or load current varies.

Types of Rectifiers

1. Rectifier circuits are basically of two types depending on the alternating voltage they take as input. They are:
   a) Single phase rectifiers
   b) Poly phase rectifiers
2. Rectifiers may be classified into two categories depending upon the period of conduction. They are:
   a) Half waver rectifier
   b) Full wave rectifier
3. Full wave rectifier may further be classified into two categories depending upon nature of the circuit connection. They are:
   c) Centre tap full wave rectifier
   d) Bridge type full wave rectifier

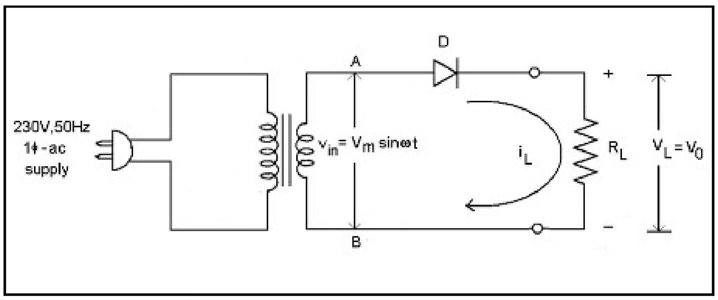
PN-Junction Half Wave Rectifier

Circuit Details

A single phase half wave rectifier circuit is shown in fig. It consists of a transformer, a diode and a load resistor R_L.

The step down transformer reduces the available a.c voltage into required level of smaller a.c voltage. The diode D and the load resistor R_L are in series with secondary of the transformer.

The primary of the transformer is connected to the single phase a.c supply. An a.c voltage is induced in the secondary of transformer by mutual induction. The voltage across the secondary is given by $v_{in} = V_m \sin \omega t$. Figure shows how this voltage varies with time. It has alternate positive and negative half cycles. Voltage V_m is the peak value of this alternating voltage.



Working

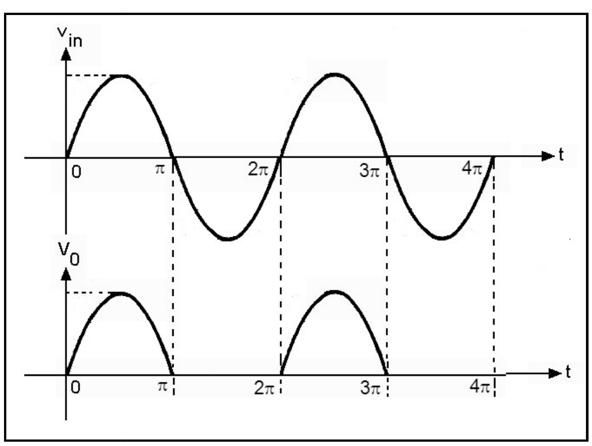
Case - I

During positive half cycle of a.c input voltage, terminal A is positive with respect to terminal B. The diode D is forward biased and it acts as closed circuit. Sinusoidal current i_L flows through the load resistor R_L in clock wise direction as shown in fig.

Case - II

During negative half cycle of the input voltage, terminal B is positive with respect to terminal A. The diode D is revere biased and it acts as open circuit. No current flows through load resistor R_L.

Thus we get a unidirectional current through R_L which flows in the form of half sinusoidal pulses. The load voltage being the product of load current and load resistance will also be in the form of half sinusoidal pulses. The input and output waveforms are shown in fig



Mathematical Analysis

Let the input voltage applied to the PN-junction diode is given by,

$$v_{in} = V_m \sin \omega t = V_m \sin\theta \qquad (\because \theta = \omega t)$$

The instantaneous load current i_L through R_L is given by,

$$i_L = \frac{V_m}{R_f + R_L}\sin\theta = I_m \sin\theta \qquad \text{for} \quad 0 \le \theta \le \pi$$

$$i_L = 0 \qquad \text{for} \quad \pi \le \theta \le 2\pi$$

Where $\qquad I_m$ = Peak value of load current $= \dfrac{V_m}{R_f + R_L}$

R_f = Forward resistance of diode

and $\qquad R_L$ = Load resistance

D.C or Average value of Output Current

The average d.c current over one complete cycle is given by,

$$I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} i_L \, d\theta$$

$$= \frac{1}{2\pi}\left[\int_0^{\pi} i_L + \int_{\pi}^{2\pi} i_L \, d\theta\right]$$

$$= \frac{1}{2\pi}\left[\int_0^{\pi} I_m \sin\theta \, d\theta\right]$$

$$= \frac{I_m}{2\pi}\left[-\cos\theta\right]_0^{\pi}$$

$$= \frac{I_m}{2\pi}\left[(-\cos\pi) - (-\cos 0)\right]$$

$$= \frac{I_m}{2\pi}\left[(-(-1)) - (-1)\right]$$

$$\therefore \quad I_{dc} = I_{avg} = \frac{I_m}{\pi}$$

Similarly the d.c or average value of output voltage across the load is given by,

$$V_{dc} = V_{avg} = I_{dc} R_L = \frac{I_m}{\pi} R_L$$

$$\therefore \quad V_{dc} = \frac{V_m}{\pi}\frac{R_L}{R_f + R_L}$$

$$= \frac{V_m}{\pi}\frac{1}{\left(1 + \frac{R_f}{R_L}\right)}$$

$$\therefore \quad V_{dc} = V_{avg} = \frac{V_m}{\pi} \qquad \left(\because \frac{R_f}{R_L} << 1\right)$$

R.M.S value or Effective value of Output Current

By the definition, the r.m.s value of load current is given by,

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i_L^2 \, d\theta}$$

$$= \sqrt{\frac{1}{2\pi}\left[\int_0^{\pi} i_L^2 \, d\theta + \int_{\pi}^{2\pi} i_L^2 \, d\theta\right]}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{\pi} (I_m \sin\theta)^2 \, d\theta}$$

$$= \sqrt{\frac{I_m^2}{2\pi}\int_0^{\pi} \sin^2\theta \, d\theta}$$

$$= \sqrt{\frac{I_m^2}{2\pi}\int_0^{\pi} \left(\frac{1-\cos 2\theta}{2}\right) d\theta}$$

$$= \sqrt{\frac{I_m^2}{4\pi}\left(\int_0^{\pi} 1 \, d\theta - \int_0^{\pi} \cos 2\theta \, d\theta\right)}$$

$$= \sqrt{\frac{I_m^2}{4\pi}(\theta)_0^{\pi}} \qquad \left(\because \int_0^{\pi} \cos 2\theta \, d\theta = 0\right)$$

$$\therefore \quad I_{rms} = \frac{I_m}{2}$$

Rectifier Efficiency

The rectifier efficiency is defined as the ratio of d.c output power to the a.c input power.

$$\therefore \ \eta = \frac{\text{D.C output power}}{\text{A.C input power}} = \frac{P_{dc}}{P_{ac}}$$

The d.c output power, $P_{dc} = I_{dc}^2 R_L = \dfrac{I_m^2 R_L}{\pi^2}$

The a.c input power, $P_{ac} = I_{rms}^2 (R_f + R_L) = \dfrac{I_m^2}{4}(R_f + R_L)$

The rectifier efficiency is given by,

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{\left(\dfrac{I_m^2 R_L}{\pi^2}\right)}{\left(\dfrac{I_m^2}{4}(R_f + R_L)\right)}$$

$$= \frac{4}{\pi^2}\frac{R_L}{R_f + R_L}$$

$$\eta = \frac{0.406}{\left(1 + \dfrac{R_f}{R_L}\right)}$$

The percentage rectifier efficiency is given by,

$$\%\eta = \frac{40.6\%}{\left(1+\frac{R_f}{R_L}\right)}$$

Note:

1. If $R_f << R_L$ the rectifier efficiency is maximum.
2. *The theoretical maximum rectifier efficiency is obtained when* $\frac{R_f}{R_L} = 0$ *and is equal to 40.6%.*

Ripple factor

The output of rectifier is not pure d.c. It contains both d.c components and a.c components (a part of a.c). A measure of such a.c components (ripples) present in the rectifier output is given by ripple factor γ .

Note: Smaller the ripple factor closer is the output to a pure d.c.

a) Definition

Mathematically ripple factor is defined as the ratio of r.m.s value of the a.c component to the average or d.c component of the output.

$$\therefore \quad \text{Ripple factor} = \frac{\text{R.M.S value of a.c component of output}}{\text{Average or d.c component of output}}$$

or

$$\gamma = \frac{V_{r\,rms}}{V_{dc}} = \frac{I_{r\,rms}}{I_{dc}}$$

b) Expression for Ripple factor

Let $I_{r\,rms}$ = R.M.S value of a.c component present in the output

I_{dc} = D.C component present in the output

I_{rms} = R.M.S value of total output

It can be noted that the output current is composed of a.c component as well as d.c component.

$$\therefore \quad I_{rms}^2 = I_{dc}^2 + I_{r\,rms}^2$$

or

$$I_{r\,rms}^2 = I_{rms}^2 - I_{dc}^2$$

Dividing by I_{dc}^2 on both sides, we get,

$$\left(\frac{I_{r\,rms}}{I_{dc}}\right)^2 = \left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1$$

$$\therefore \quad \text{Ripple factor}, \gamma = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

Note: This is the general expression for ripple factor and can be used for any rectifier circuit.

c) Ripple factor for Half Wave Rectifier

For a half wave rectifier, we have,

$$I_{rms} = \frac{I_m}{2} \text{ and } I_{dc} = \frac{I_m}{\pi}$$

$$\gamma = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

$$\therefore \quad \gamma = \sqrt{\left(\frac{\frac{I_m}{2}}{\frac{I_m}{\pi}}\right)^2 - 1} = \sqrt{\left(\frac{\pi}{2}\right)^2 - 1} = \sqrt{1.467}$$

$$\therefore \quad \gamma = 1.21$$

This indicates that the ripple contents in the output are 1.21 times the d.c component i.e. 121% of d.c component.

Peak Inverse Voltage (PIV)

It is defined as the maximum voltage across the diode in the reverse direction.

or

It is the reverse voltage that a diode can withstand without destroying the junction, during the non conducting period.

In a half wave rectifier, the reverse voltage across the diode during non-conducting period equals the maximum value of transformer secondary voltage V_m.

$\therefore$ PIV of diode = V_m = Maximum value of transformer secondary voltage.

*Note: The diode must be selected based on PIV rating and circuit specifications.

Advantages of Half Wave Rectifier

1. *It is simple and low cost circuit.*
2. *It requires only one diode.*

Disadvantages of Half Wave Rectifier

1. *Low rectification efficiency.*
2. *The ripple factor of half wave rectifier is 1.21, which is quite high. The output contains lot of a.c components. Therefore an elaborate filtering is required to produce steady direct current.*
3. *D.C saturation of transformer core, which results when the current in the secondary side of transformer flows in the same direction, leads to hysteresis losses and harmonics in the output.*
4. *The a.c supply delivers power only half the time. Therefore the output is low.*

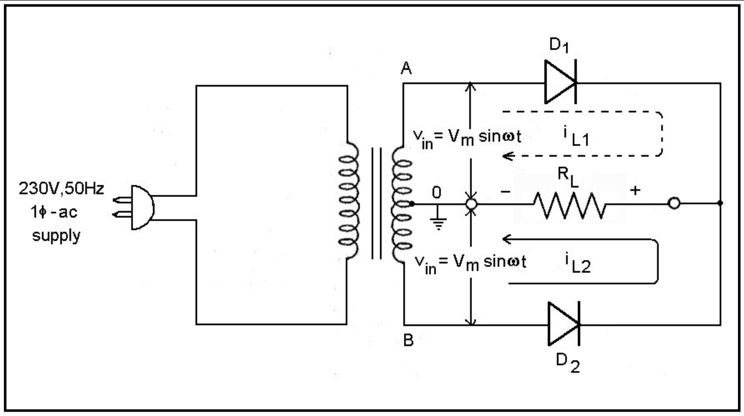
Centre tap Full Wave Rectifier

Circuit Details

The centre tap full wave rectifier circuit is shown in fig. In order to rectify both the half cycles of a.c input, two diodes are used in this circuit. A centre tapped secondary winding AB is used with two diodes such that, diode D_1 utilises the a.c voltage appearing across the upper half of secondary winding 0A for rectification while diode D_2 uses the lower half winding 0B.

*Note:

1. *The full wave rectifier conducts during both positive and negative half cycles of input supply.*
2. *Each diode uses one half cycle of input a.c voltage.*
3. *In this circuit the centre of the transformer secondary is taken as reference point (earth).*



Working

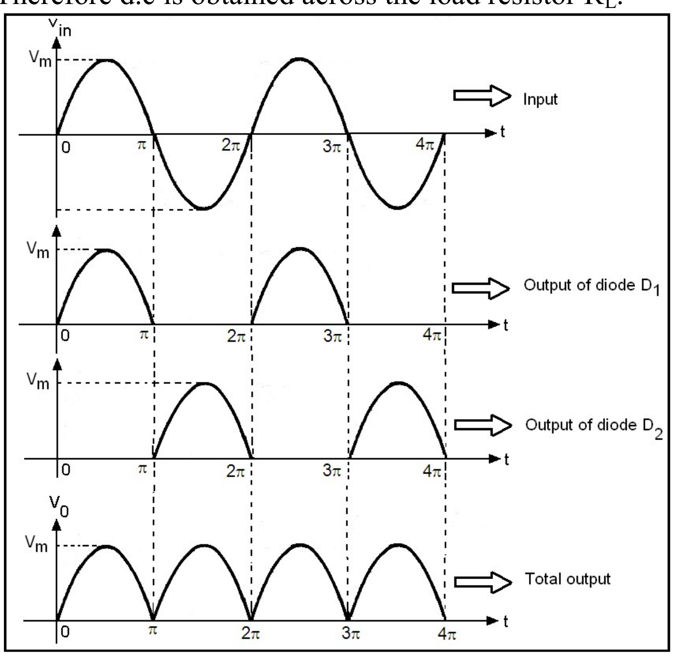
Case - I

During positive half cycle of a.c input voltage, terminal A is positive with respect to the earth and terminal B is negative. This makes the diode D_1 forwarded biased and diode D_2 reverse biased. Therefore diode D_1 conducts and diode D_2 non-conducting. Current takes the path $A \rightarrow D_1 \rightarrow R_L \rightarrow 0 \rightarrow A$. In other words the conventional current flows through diode D_1, load resistor R_L and upper half of secondary winding 0A as shown by the dotted arrows.

Case - II

During negative half cycle of a.c input voltage terminal A is negative with respect to earth and terminal B is positive. The diode D_2 conducts and D_1 does not. The current takes the path $B \rightarrow D_2 \rightarrow R_L \rightarrow 0 \rightarrow B$. In other words the conventional current flows through diode D_2, load resistor R_L and lower half of secondary winding 0B as shown by the solid arrows.

Thus the current in the load resistor R_L is in the same direction for both half cycles of input a.c voltage. Therefore d.c is obtained across the load resistor R_L.



Mathematical Analysis

Let the input voltage v_{in} is given by,

$$v_{in} = V_m \sin\omega t = V_m \sin\theta$$

The instantaneous current i_{L1} through diode D_1 and load resistor R_L is given by,

$$i_{L1} = I_m \sin\theta \qquad \text{for } 0 \le \theta \le \pi$$

$$i_{L1} = 0 \qquad \text{for } \pi \le \theta \le 2\pi$$

Similarly the instantaneous current i_{L2} through diode D_2 and load resistor R_L is given by,

$$i_{L2} = 0 \qquad \text{for } 0 \le \theta \le \pi$$

$$i_{L2} = -I_m \sin\theta \qquad \text{for } \pi \le \theta \le 2\pi$$

The total current flowing through R_L is the sum of two currents i_{L1} and i_{L2} i.e.

$$i_L = i_{L1} + i_{L2}$$

D.C or Average value of Output Current

The average d.c current over one half cycle is given by,

$$I_{dc} = \frac{1}{\pi}\int_0^{\pi} i_L \, d\theta$$

$$= \frac{1}{\pi}\left[\int_0^{\pi} I_m \sin\theta \, d\theta\right]$$

$$= \frac{I_m}{\pi}\left[-\cos\theta\right]_0^{\pi}$$

$$= \frac{I_m}{\pi}\left[(-\cos\pi) - (-\cos 0)\right]$$

$$= \frac{I_m}{\pi}\left[(-(-1)) - (-1)\right]$$

$$\therefore \qquad I_{dc} = I_{avg} = \frac{2I_m}{\pi}$$

Similarly the d.c or average value of output voltage across the load is given by,

$$V_{dc} = V_{avg} = I_{dc}R_L = \frac{2I_m}{\pi} R_L$$

$$\therefore \qquad V_{dc} = \frac{2V_m}{\pi} \frac{R_L}{R_f + R_L}$$

$$= \frac{2V_m}{\pi} \frac{1}{\left(1 + \frac{R_f}{R_L}\right)}$$

$$\therefore \qquad V_{dc} = V_{avg} = \frac{2V_m}{\pi} \qquad \left(\because \frac{R_f}{R_L} << 1\right)$$

R.M.S value or Effective value of Output Current

By the definition, the r.m.s value of load current is given by,

$$I_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} i_L{}^2 \, d\theta}$$

$$= \sqrt{\frac{1}{\pi}\int_0^{\pi} (I_m \sin\theta)^2 \, d\theta}$$

$$= \sqrt{\frac{I_m{}^2}{\pi}\int_0^{\pi} \sin^2\theta \, d\theta}$$

$$= \sqrt{\frac{I_m{}^2}{\pi}\int_0^{\pi} \left(\frac{1-\cos 2\theta}{2}\right) d\theta}$$

$$= \sqrt{\frac{I_m{}^2}{2\pi}\left(\int_0^{\pi} 1\, d\theta - \int_0^{\pi} \cos 2\theta\, d\theta\right)}$$

$$= \sqrt{\frac{I_m{}^2}{2\pi}(\theta)_0^{\pi}}$$

$$\therefore \qquad I_{rms} = \frac{I_m}{\sqrt{2}}$$

Rectifier Efficiency

The d.c output power,

$$P_{dc} = I_{dc}{}^2 R_L = \left(\frac{2I_m}{\pi}\right)^2 R_L = \frac{4I_m{}^2}{\pi^2} R_L$$

The a.c input power,

$$P_{ac} = I_{rms}{}^2 (R_f + R_L) = \left(\frac{I_m}{\sqrt{2}}\right)^2 (R_f + R_L) = \frac{I_m{}^2}{2}(R_f + R_L)$$

Therefore the rectifier efficiency is given by,

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{\left(\frac{4I_m{}^2}{\pi^2} R_L\right)}{\left(\frac{I_m{}^2}{2}(R_f + R_L)\right)} = \frac{8}{\pi^2}\frac{R_L}{R_f + R_L}$$

$$\therefore \qquad \eta = \frac{0.8106}{\left(1 + \frac{R_f}{R_L}\right)}$$

The percentage rectifier efficiency is given by,

$$\therefore \qquad \%\eta = \frac{81.06\%}{\left(1 + \frac{R_f}{R_L}\right)}$$

*Note: The theoretical maximum efficiency is obtained when $(R_f/R_L) = 0$ and is equal to 81.06%

Ripple factor for Full Wave Rectifier

For full wave rectifier,

$$I_{rms} = \frac{I_m}{\sqrt{2}} \quad \text{and} \quad I_{dc} = \frac{2I_m}{\pi}$$

$$\therefore \qquad \gamma = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1} = \sqrt{\left(\frac{\frac{I_m}{\sqrt{2}}}{\frac{2I_m}{\pi}}\right)^2 - 1}$$

$$= \sqrt{\left(\frac{\pi}{2\sqrt{2}}\right)^2 - 1} = \sqrt{\frac{\pi^2}{8} - 1} = \sqrt{0.233}$$

$$\therefore \qquad \gamma = 0.48$$

Peak Inverse Voltage (PIV)

Peak inverse voltage is the maximum possible voltage across a diode when it is reverse biased. Consider that diode D_1 is in forward biased i.e. conducting and diode D_2 is reverse biased i.e. non-conducting. In this case a voltage V_m is developed across the load resistor R_L. Now the voltage across the diode D_2 is the sum of the voltage across load resistor R_L and voltage across the lower half of transformer secondary V_m. hence PIV of diode $D_2 = V_m + V_m = 2\ V_m$. Similarly PIV of diode D_1 is $2V_m$.

Advantages of Centre tap Full Wave Rectifier

1. *The d.c load current in case of full wave rectifier is twice to that in half wave rectifier.*
2. *Rectification efficiency of a full wave rectifier is twice to that of half wave rectifier.*
3. *Lower ripple factor.*
4. *Easy filtering due to high ripple frequency (2f).*
5. *The d.c saturation of the core is avoided as current flows through the two halves of the centre tapped secondary of the power transformer in opposite directions.*

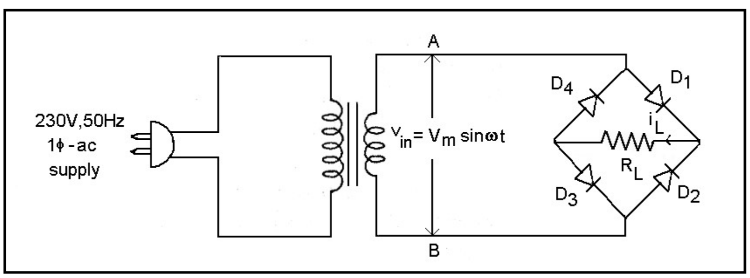
Disadvantages Centre tap Full Wave Rectifier

1. *For the same d.c output voltage, the transformer secondary voltage required in full wave rectifier is twice that of required for half wave rectifier.*
2. *The diodes used must have high peak inverse voltage.*
3. *It is difficult to locate the centre tap on the secondary winding.*

Bridge type Full Wave Rectifier

Circuit Details

A bridge type full wave rectifier circuit is shown in fig. It is so named because four diodes are connected in Wheatstone bridge form. To one diagonal of the bridge, the a.c voltage is applied through a transformer and the rectified d.c voltage is taken across the other diagonal of the bridge. The main advantage of this is that it does not require a centre tap on the secondary winding of the transformer.



**Note:*

1. *To overcome few drawbacks of centre tap full wave rectifier, a bridge type full wave rectifier is used.*
2. *The most commonly used rectifier for electronic d.c power supply is bridge type full wave rectifier.*

Working

Case - I

During positive half cycle of a.c input voltage, terminal A is positive with respect to B. The diodes D_1 and D_3 are forward biased and D_2 and D_4 are reverse biased. This makes the diodes D_1 and D_3 are conducting and the diodes D_2 and D_4 are non conducting. The current flows through the secondary winding, diode D_1, load resistor R_L and diode D_3 as shown in fig. 1.9(a).

Case - II

During negative half cycle of a.c input voltage, terminal B is positive with respect to A. The diodes D_2 and D_4 are forward biased and D_1 and D_3 are reverse biased. This makes the diodes D_2 and D_4 are conducting and the diodes D_1 and D_3 are non conducting. The current flows through the secondary winding, diode D_2, load resistor R_L and diode D_4 as shown in fig. 1.9(a).

Thus the current in the load resistor R_L is in the same direction for both half cycles of input a.c voltage. Therefore d.c is obtained across the load resistor R_L.

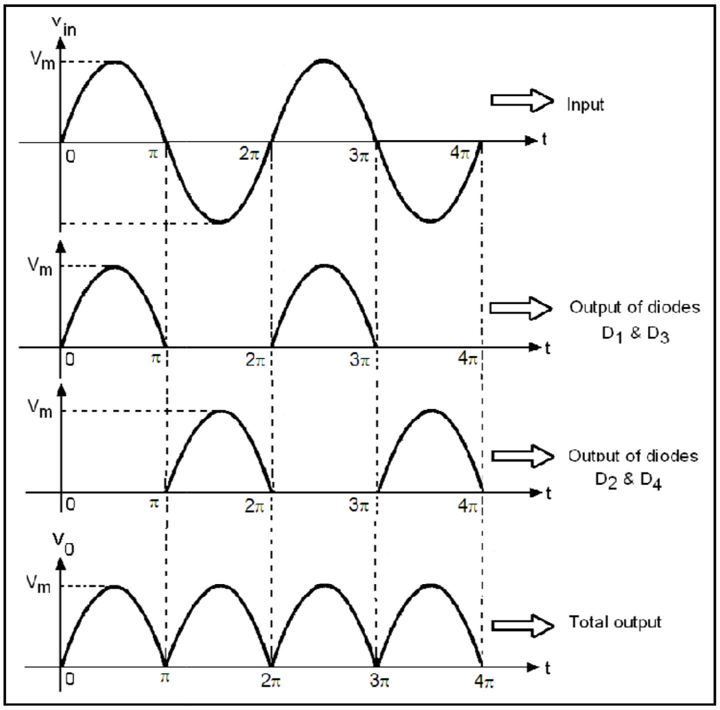


Fig. 1.9(b)

*Note: The output wave forms are exactly the same as that obtained for the centre tap full wave rectifier circuit as shown in fig. 1.9(b).

Mathematical Analysis

The derivations for bridge type full wave rectifier is same as that of centre tap full wave rectifier circuit, except

$$I_m = \frac{V_m}{2R_f + R_L}$$

So the only modification is that instead of R_f, which is forward resistance of each diode, the term $2R_f$ appears in the denominator.

The remaining expressions are identical to those derived for centre tap full wave rectifier and reproduced for the convenience of the reader.

Table: 1

Sl.No.	Parameters	Expressions
1.	D.C or average value of output current	$I_{dc} = \frac{2I_m}{\pi}$
2.	R.M.S or effective value of output current	$I_{rms} = \frac{I_m}{\sqrt{2}}$

3.	A.C input power	$P_{ac} = \frac{4I_m^2}{\pi^2} R_L$
4.	D.C output power	$P_{ac} = \frac{I_m^2}{2}(2R_f + R_L)$
5.	Rectifier efficiency	$\eta = \frac{0.8106}{\left(1 + \frac{2R_f}{R_L}\right)}$
6.	Ripple factor	$\gamma = 0.48$
7.	PIV of each diode	V_m

Advantages of Bridge type Full Wave Rectifier

1. *Transformer with centre tap in secondary is not required. This leads to reduction in cost and weight.*
2. *PIV rating is one half of the centre tap diode, so smaller and cheaper diodes can be used.*

Disadvantage of Bridge type Full Wave Rectifier

1. *The only disadvantage of bridge rectifier is it requires four diodes as compared to centre tap full wave rectifier.*

Bridge type Full Wave Rectifier

Sl.No.	Parameters	Half wave rectifier	Centre tap full wave rectifier	Bridge type full wave rectifier
1.	I_{dc}	$\frac{I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$
2.	V_{dc}	$\frac{V_m}{\pi}$	$\frac{2V_m}{\pi}$	$\frac{2V_m}{\pi}$
3.	I_{rms}	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
4.	%Efficiency	40.6%	81.06%	81.06%
5.	Ripple Factor	1.21	0.482	0.482
6.	Ripple frequency	f	2f	2f
7.	Peak inverse Voltage	V_m	$2V_m$	V_m
8.	Voltage regulation	$\frac{R_f}{R_L}$	$\frac{R_f}{R_L}$	$\frac{2R_f}{R_L}$

9.	Number of diodes	1	2	4
10.	Necessity of transformer	No	Yes	No
11.	Cost	Low	Costly	Less costly
12.	Use	Simple circuits	Used in low voltage, high current d.c power supply circuits.	Used in high voltage, low current d.c power supply circuits.

Need for a Filter Circuit in power supply

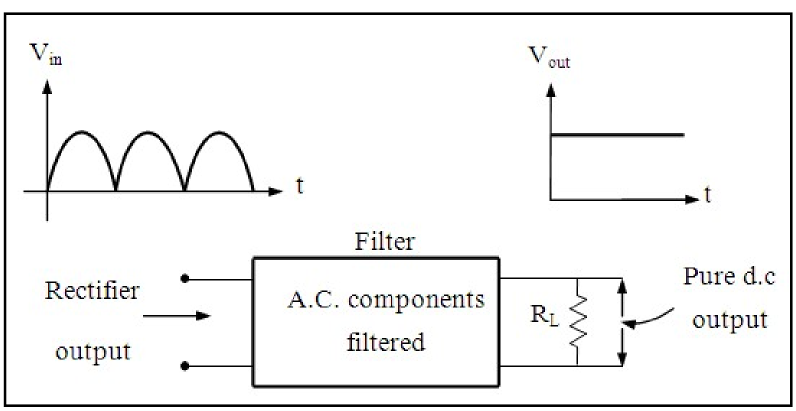
The output of a rectifier consists of a d.c component and an a.c component (also known as ripple). The a.c component is undesirable and must be kept away from the load. To do so a filter circuit is used which removes the a.c component and allows only the d.c component to reach the load.

A filter circuit is a device which removes the a.c component of rectifier output but allows the d.c component to reach the load.

Obviously, a filter circuit should be connected between the rectifier and the load as shown in fig. A filter circuit is generally a combination of inductors (L) and capacitors(C). The filtering action of L and C depends upon the basic electrical properties.

*Note:

1. *The main function of filter is to minimize the ripple content in the rectifier output.*
2. *The ideal inductor acts as short circuit for d.c, therefore it cannot be placed in shunt across the load; otherwise the d.c will be shorted. Hence, in a filter circuit the inductor is always connected in series with the load.*
3. *Similarly, the ideal capacitor acts as open circuit for d.c, i.e. it blocks d.c, and therefore it cannot be connected in series with the load. It is always connected in parallel with the load.*
4. *The inductor used in filter circuits is also called choke.*
5. *The filter circuit is also known as smoothing circuit.*



Shunt Capacitor Filter

Types of Filter Circuits

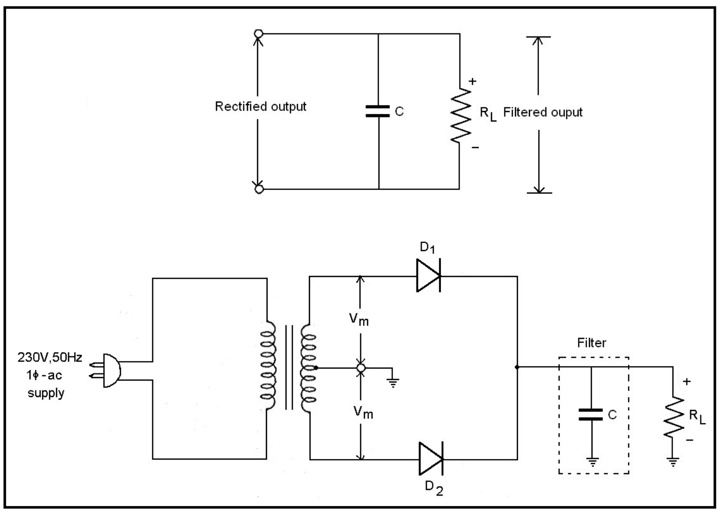
The commonly used filter circuits in the power supply circuits are listed below.

1. *Shunt capacitor filter*
2. *Series inductor filter*
3. *L-section (LC) or inductor input filter*
4. *π -section (CLC) or capacitor input filter*
5. *CRC filter*

Circuit Details

Fig. shows a typical capacitor filter circuit. Fig. shows a full wave rectifier with a capacitor filter. The filter uses a single capacitor connected in parallel with the load resistor R_L. In order to minimize the ripple in the output, the capacitor C used in the filter circuit is quite large of the order of tens of microfarads (μF).

*Note: Electrolyte capacitor which is polarized is generally used in filter circuits.



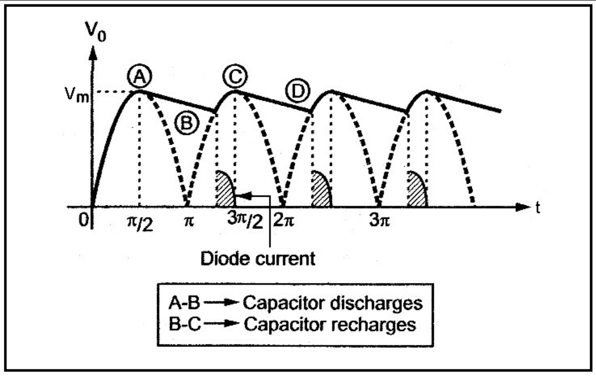
Working

Immediately when power is turned on, the capacitor C gets charged through forward biased diode D_1 to V_m, during first quarter cycle of the rectified output voltage.

In the next quarter cycle from $\frac{\pi}{2}$ to π, the input voltage falls below the capacitor voltage (V_m). As a result the diode D_1 becomes reverse biased and stops conducting. So the capacitor starts discharging through R_L and supplies the load current. It discharges to point B as shown in fig.

At point B, lying in the quarter cycle π to $\frac{3\pi}{2}$ of the rectified output voltage, the input voltage exceeds capacitor voltage, making D_2 forward biased. This charges capacitor back to V_m at point C.

The time required by capacitor C to charge to V_m is quite small and only for this period, diode D_2 is conducting. Again at point C, diode D_2 stops conducting and capacitor starts discharging through R_L and supplies the load current. It discharges to point D shown in fig. At this point the diode D_1 conducts to charge capacitor back to V_m.



This process is repeated again and again and the output waveform becomes ABCD. Fig shows the load voltage variation with a.c voltage. It is obvious from the fig. that nearly constant d.c voltage appears across R_L at all times.

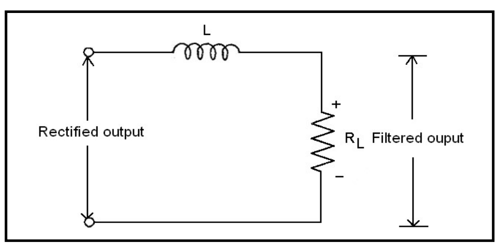
*Note:

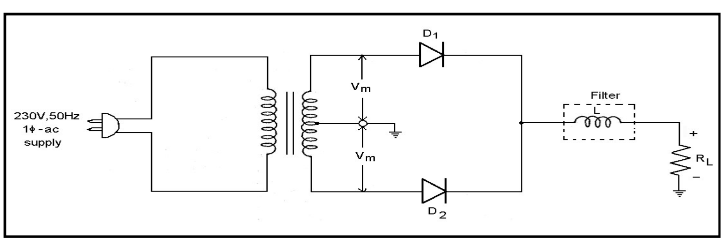
1. *The discharging time constant (CR_L) is large usually 100 times more than charging time, hence the condenser does not have sufficient time to discharge appreciable. Due to this fact the voltage of condenser C decreases slightly.*
2. *The diodes are not conducting for the entire half cycle. The diode currents are shown in fig.*
3. *When the capacitor is discharging through the load resistor R_L, both the diodes are non-conducting. The capacitor supplies the load current.*

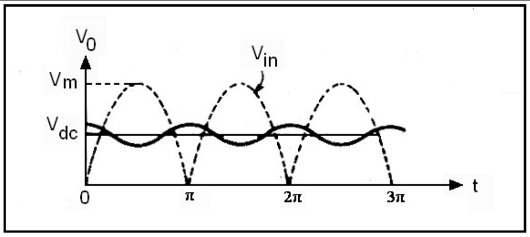
Series Inductor Filter

Circuit Details

Fig. shows a typical series inductor filter circuit. Fig. shows a full wave rectifier with a series inductor filter. The filter uses single inductor connected in series with the load. An inductor has the fundamental property of opposing any change in current flowing through it. This property is used in the series inductor filter.







Working

Whenever an a.c flows through an inductor, self induced e.m.f or back e.m.f is induced in the inductor which prevents the very cause of its production i.e., alternating current to flow through it according to Lenz's law. As a result the inductor permits d.c to flow through it and prevents a.c.

The working of series inductor filter can be understood in another way also as follows:

1. *For d.c and low frequency ripple components, X_L is low, thus it permits d.c and low frequency components.*
2. *For high frequency ripple components, X_L is very high, thus it completely blocks it.*

Therefore the output of inductor contains d.c and low frequency components.

Fig shows the output waveform obtained by using series inductor filter or choke filter with full wave rectifier.

*Note:

1. *This filter can only be used with a full wave rectifier since it requires current to flow at all times.*
2. *The operation of a series inductor filter depends upon the current through it. Higher the current flowing through it, the better is its filtering action.*
3. *The inductor filter is suitable for heavy loads (R_L=low).*

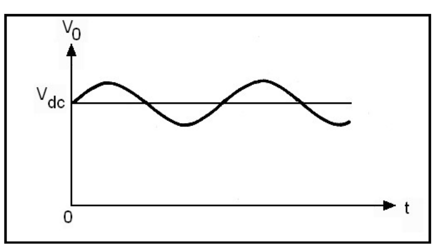
L-Section (LC) or Choke Input Filter

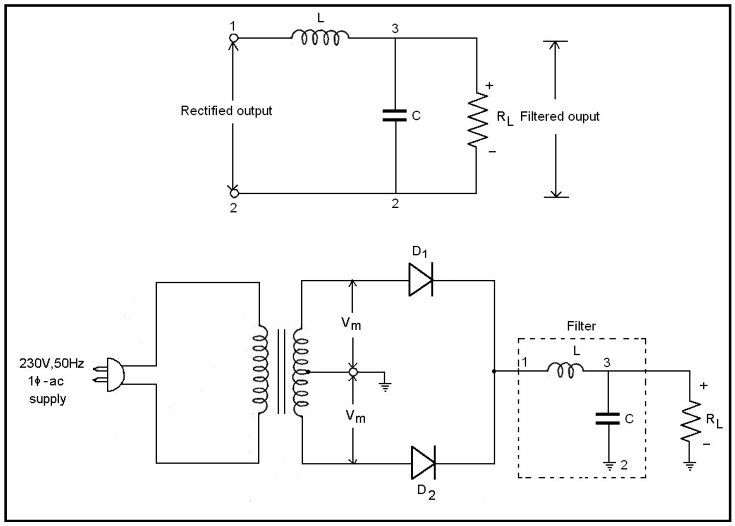
Circuit Details

We have seen that series inductor filter and shunt capacitor filter are not much efficient to provide low ripple at all loads. The shunt capacitor filter has low ripple at small loads while series inductor filter has low ripple at heavy loads. A combination of these two filters may be selected to make the ripple independent of load resistor R_L. The resulting filter is called L-section or choke input filter. This name is due to the fact that the inductor and capacitor are connected as an inverted L.

Fig shows a typical choke input filter circuit. It consists of a choke L connected in series with the rectifier output and a filter capacitor C across the load. A full wave rectifier with choke input filter is shown in fig. 1.13(b). Only a single filter section is shown, but several identical sections are often used to reduce the pulsations effectively as possible.

*Note: The a.c reactance of the capacitor is made sufficiently small compared with R_L so that essentially all of the alternating current passes through the capacitor and none through R_L. The ripple factor is thus reduced very much.





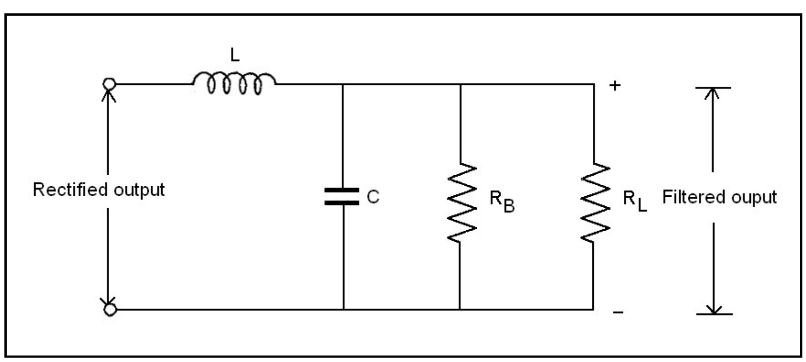
Working

The pulsating output of the rectifier is applied across terminals 1 and 2 of the filter circuit. As discussed before, the pulsating output of rectifier contains a.c and d.c components. The choke offers high opposition to the passage of a.c component but negligible opposition to the d.c component. The result is that most of the a.c component appears across the choke while whole of d.c component passes through the choke on its way to load. This results in the reduced pulsations at terminal 3.

At terminal 3, the rectifier output contains d.c component and remaining part of a.c component. Since the capacitor C is connected across the load, it bypasses the a.c component but prevents the d.c component to flow through it. Therefore, only d.c component reaches the load. In this way, the filter circuit has filtered out the a.c component from the rectifier output, allowing d.c component to reach the load.

Bleeder Resister

A bleeder resistor is a resistor placed in parallel with a high voltage supply for the purpose of discharging the energy stored in the filter capacitors or other components that store electrical energy when the equipment is turned OFF.



A bleeder resistor is essential for the power supply circuits that include the choke filters for smoothening action. Since the inductor operations depends on the current there should be always a flow of minimum current through the inductor for better functioning of filtering action.

Otherwise a large back e.m.f is developed across the choke, which may be in excess of PIV rating of diodes and/or maximum voltage rating of the capacitor C. Thus this back e.m.f is harmful to the diodes and capacitor. To eliminate the back e.m.f developed across the choke, the current through it must be continuous. This is achieved by connecting a bleeder resistor across the output terminals.

Advantages of Bleeder Resistor

1. It improves the filtering action by maintaining a minimum current through the choke.
2. It improves the voltage regulation of the supply by acting as preload on the supply.
3. It provides the safety to the persons handling the equipments, (when the supply is switched OFF, the capacitor retains its charge for some time, this voltage may be dangerous for people working with equipment) by acting as discharging path for capacitors.

π-section (CLC) or Capacitor Input Filter

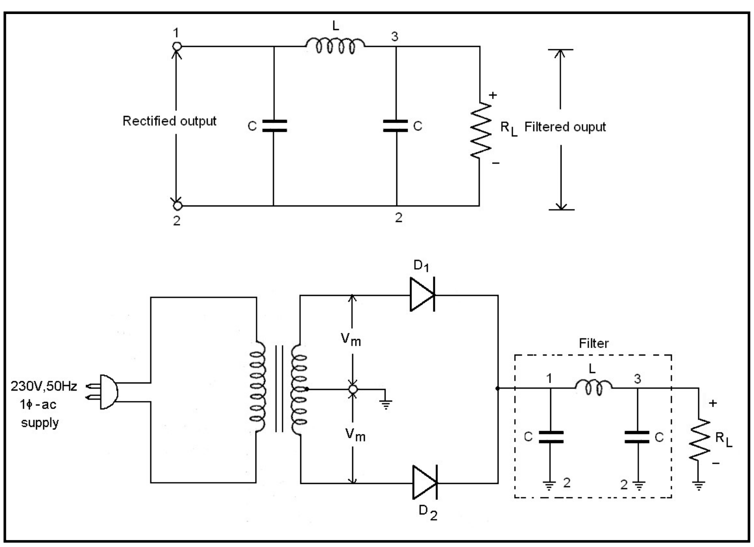
Circuit Details

Fig shows a typical capacitor input filter or $\pi - \text{filter}$. It consists of a filter capacitor C_1 connected across the rectifier output, a choke L in series and another filter capacitor C_2 connected across the load. Only one filter section is shown but several identical sections are often used to improve the smoothing action.

Working

The pulsating output from the rectifier is applied across the input terminals (i.e. terminal 1 and 2) of the filter. The filtering action of the three components viz C_1, L and C_2 of this filter is described below:

a. *The filter capacitor C_1 offers low reactance to a.c component of rectifier output while it offers infinite reactance to the d.c component. Therefore, capacitor C_1 bypasses an appreciable amount of a.c component while the d.c component continues its journey to the choke L.*
b. *The choke L offers high reactance to the a.c component but it offers almost zero reactance to the d.c component. Therefore, it allows the d.c component to flow through it, and blocks the a.c component which could not be by-passed by the capacitor C_1.*
c. *The filter capacitor C_2 bypasses the a.c component which could not be by-passed by inductor L. Therefore, only d.c component appears across the load.*



CRC Filter

The disadvantages of π-section filter are the cost, weight, size and external field produced by the series inductor. These disadvantages can be overcome by replacing the series inductor with a series resistor of 100 to 200 Ω. It is then called capacitor-input RC filter or CRC filter.

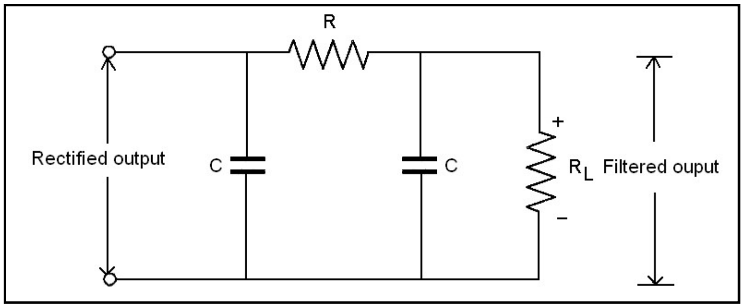


Fig.shows a CRC filter connected between the output of rectifier and the load resistor. By deliberate design, R is much greater than X_C at the ripple frequency. Therefore the ripple is dropped across the series resistance instead of across the load resistor. Typically, R is at least 10 times greater than X_C. This means that each section attenuates the ripple by a factor of at least 10. The function of capacitor is same as in CLC filter.

Advantages

- Low cost
- Small size
- Less weight
- No external field due to series inductor

Disadvantages

- The main disadvantage of the CRC filter is the loss of d.c voltage across the R. This means that the RC is suitable only for light loads.
- The voltage regulation becomes poorer.
- This circuit requires adequate ventilation to conduct away the heat produced in the resistor.

UNIT- II: - TRANSISTOR CHARACTERISTICS: BJT & FET

3.1 INTRODUCTION

A bipolar junction transistor (BJT) is a three terminal device in which operation depends on the interaction of both majority and minority carriers and hence the name bipolar. The BJT is analogues to vacuum triode and is comparatively smaller in size. It is used as amplifier and oscillator circuits, and as a switch in digital circuits. It has wide applications in computers, satellites and other modern communication systems.

3.2 CONSTRUCTION OF BJT AND ITS SYMBOLS

The **Bipolar Transistor** basic construction consists of two PN-junctions producing three connecting terminals with each terminal being given a name to identify it from the other two. These three terminals are known and labelled as the Emitter (E), the Base (B) and the Collector (C) respectively. There are two basic types of bipolar transistor construction, PNP and NPN, which basically describes the physical arrangement of the P-type and N-type semiconductor materials from which they are made.

Transistors are three terminal active devices made from different semiconductor materials that can act as either an insulator or a conductor by the application of a small signal voltage. The transistor's ability to change between these two states enables it to have two basic functions: "switching" (digital electronics) or "amplification" (analogue electronics).

Then bipolar transistors have the ability to operate within three different regions:

1. Active Region - the transistor operates as an amplifier and $I_c = \beta . I_b$
2. Saturation - the transistor is "fully-ON" operating as a switch and $I_c = I(saturation)$
3. Cut-off - the transistor is "fully-OFF" operating as a switch and $I_c = 0$

Bipolar Transistors are current regulating devices that control the amount of current flowing through them in proportion to the amount of biasing voltage applied to their base terminal acting like a current-controlled switch. The principle of operation of the two transistor types PNP and NPN, is exactly the same the only difference being in their biasing and the polarity of the power supply for each type (fig 1).

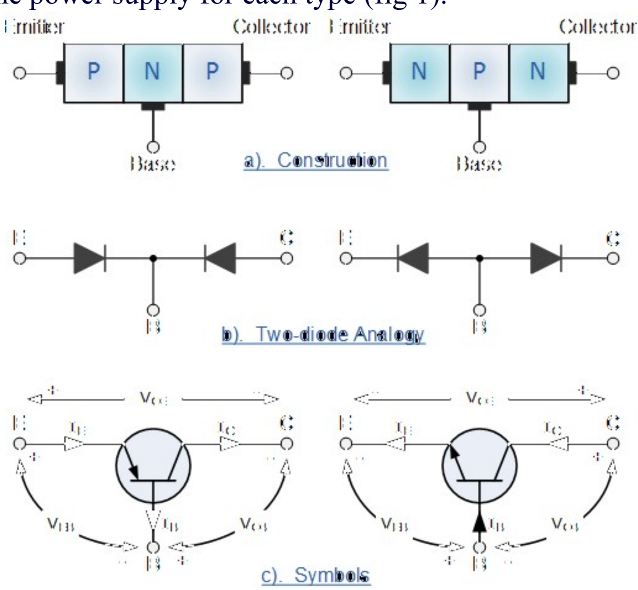


Fig 3.1 Bipolar Junction Transistor Symbol

The construction and circuit symbols for both the PNP and NPN bipolar transistor are given above with the arrow in the circuit symbol always showing the direction of "conventional current flow" between the base terminal and its emitter terminal. The direction of the arrow always points from the positive P-type region to the negative N-type region for both transistor types, exactly the same as for the standard diode symbol.

3.3 TRANSISTOR CURRENT COMPONENTS:

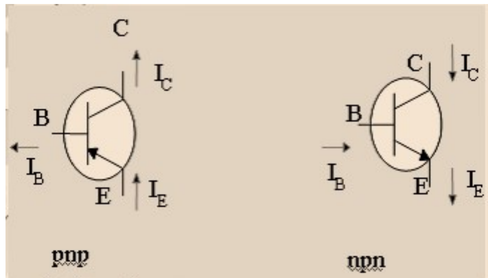


Fig 3.2 Bipolar Junction Transistor Current Components

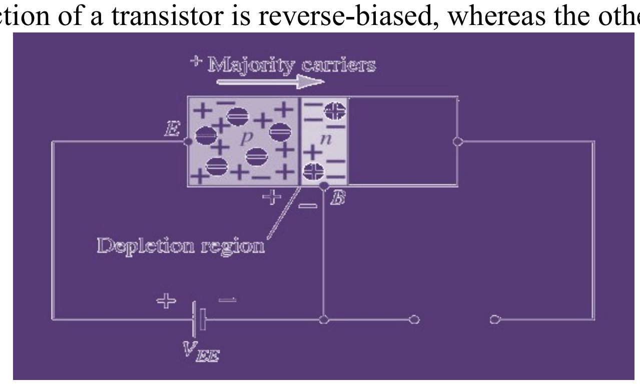
The above fig 3.2 shows the various current components, which flow across the forward biased emitter junction and reverse- biased collector junction. The emitter current I_E consists of hole current I_{p_E} (holes crossing from emitter into base) and electron current I_{n_E} (electrons crossing from base into emitter).The ratio of hole to electron currents, I_{p_E} / I_{n_E}, crossing the emitter junction is proportional to the ratio of the conductivity of the p material to that of the n material. In a transistor, the doping of that of the emitter is made much larger than the doping of the base. This feature ensures (in p-n-p transistor) that the emitter current consists an almost entirely of holes. Such a situation is desired since the current which results from electrons crossing the emitter junction from base to emitter do not contribute carriers, which can reach the collector.

Not all the holes crossing the emitter junction J_E reach the collector junction J_C because some of them combine with the electrons in n-type base. If I_{p_C} is hole current at junction J_C there must be a bulk recombination current (I_{p_E} - I_{p_C}) leaving the base.

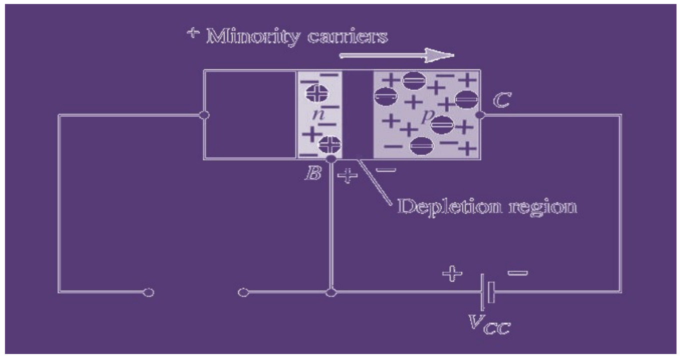
Actually, electrons enter the base region through the base lead to supply those charges, which have been lost by recombination with the holes injected in to the base across J_E. If the emitter were open circuited so that I_E=0 then I_{p_C} would be zero. Under these circumstances, the base and collector current I_C would equal the reverse saturation current I_{CO}. If $I_E \neq 0$ then I_C= I_{CO}- I_{p_C}.

For a p-n-p transistor, I_{CO} consists of holes moving across J_C from left to right (base to collector) and electrons crossing J_C in opposite direction. Assumed referenced direction for I_{CO} i.e. from right to left, then for a p-n-p transistor, I_{CO} is negative. For an n-p-n transistor, I_{CO} is positive. The basic operation will be described using the p-n-p transistor. The operation of the p-n-p transistor is exactly the same if the roles played by the electron and hole are interchanged.

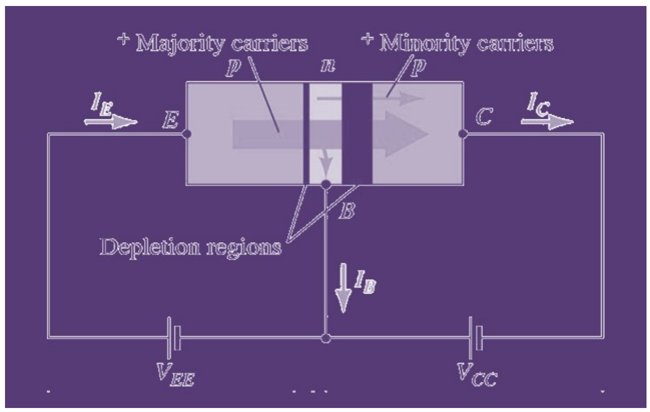
One p-n junction of a transistor is reverse-biased, whereas the other is forward-biased.



3.3a Forward-biased junction of a pnp transistor



3.3b Reverse-biased junction of a pnp transistor



3.3c Both biasing potentials have been applied to a pnp transistor and resulting majority and minority carrier flows indicated.

Majority carriers (+) will diffuse across the forward-biased p-n junction into the n-type material. A very small number of carriers (+) will through n-type material to the base terminal. Resulting I_B is typically in order of microamperes. The large number of majority carriers will diffuse across the reverse-biased junction into the p-type material connected to the collector terminal

Applying KCL to the transistor :

$$I_E = I_B + I_C$$

The comprises of two components – the majority and minority carriers

$$I_C = I_{Cmajority} + I_{COminority}$$

I_{CO} – I_C current with emitter terminal open and is called leakage current

3.4 Bipolar Transistor Configurations

As the **Bipolar Transistor** is a three terminal device, there are basically three possible ways to connect it within an electronic circuit with one terminal being common to both the input and output. Each method of connection responding differently to its input signal within a circuit as the static characteristics of the transistor varies with each circuit arrangement.

1. Common Base Configuration - has Voltage Gain but no Current Gain.
2. Common Emitter Configuration - has both Current and Voltage Gain.
3. Common Collector Configuration - has Current Gain but no Voltage Gain.

3.5 COMMON-BASE CONFIGURATION

Common-base terminology is derived from the fact that the: base is common to both input and output of the configuration. Base is usually the terminal closest to or at ground potential. Majority carriers can cross the reverse-biased junction because the injected majority carriers will appear as minority carriers in the n-type material. All current directions will refer to conventional (hole) flow and the arrows in all electronic symbols have a direction defined by this convention.

Note that the applied biasing (voltage sources) are such as to establish current in the direction indicated for each branch.

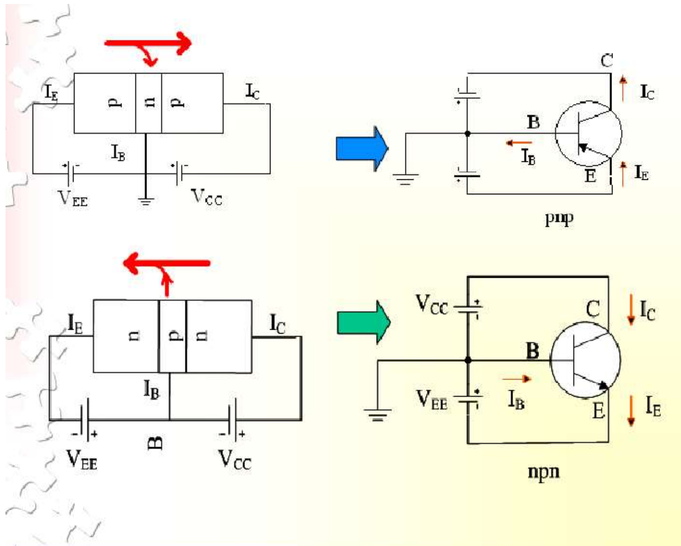


Fig 3.4 CB Configuration

To describe the behaviour of common-base amplifiers requires two set of characteristics:

1. Input or driving point characteristics.
2. Output or collector characteristics

The output characteristic has 3 basic regions:

1. Active region –defined by the biasing arrangements
2. Cutoff region – region where the collector current is 0A
3. Saturation region- region of the characteristics to the left of VCB = 0V

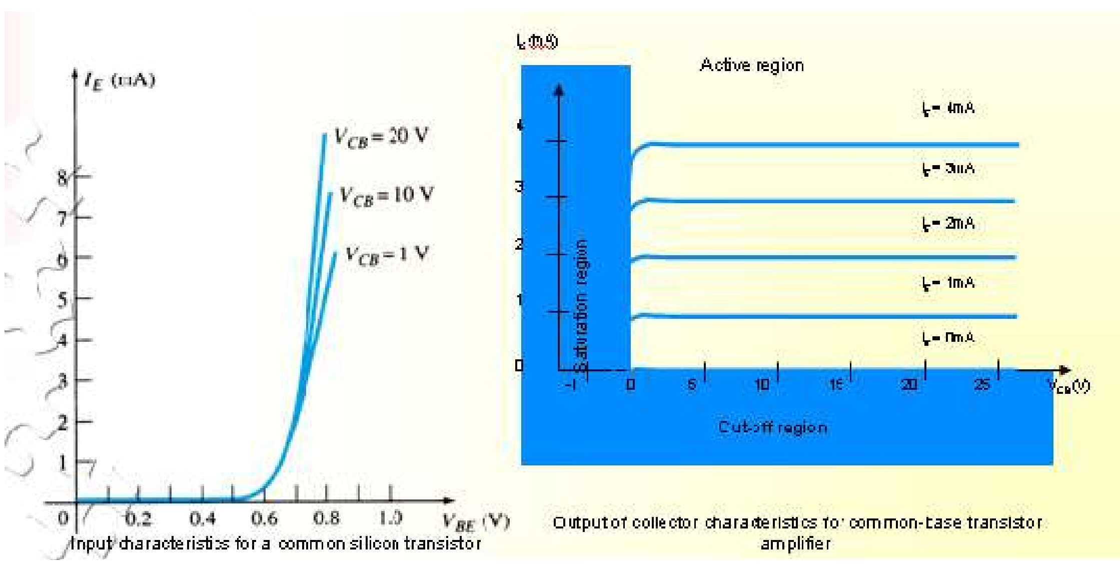
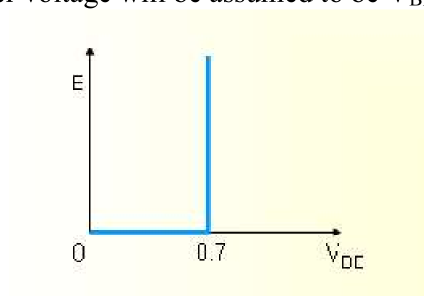


Fig 3.5 CB Input-Output Characteristics

Active region	Saturation region	Cut-off region
•I_E increased, I_C increased •BE junction forward bias and CB junction reverse bias •Refer to the graf, $I_C \approx I_E$ •I_C not depends on V_{CB} •Suitable region for the transistor working as amplifier	• BE and CB junction is forward bias • Small changes in V_{CB} will cause big different to I_C • The allocation for this region is to the left of V_{CB}= 0 V.	• Region below the line of I_E=0 A • BE and CB is reverse bias • no current flow at collector, only leakage current

The curves (output characteristics) clearly indicate that a first approximation to the relationship between I_E and I_C in the active region is given by $I_C \approx I_E$. Once a transistor is in the 'on' state, the base-emitter voltage will be assumed to be V_{BE} = 0.7V



In the dc mode the level of I_C and I_E due to the majority carriers are related by a quantity called alpha $\alpha = \alpha_{dc}$

$$I_C = I_E + I_{CBO}$$

It can then be summarize to $I_C = I_E$ (ignore I_{CBO} due to small value)

For ac situations where the point of operation moves on the characteristics curve, an ac alpha defined by α_{ac} Alpha a common base current gain factor that shows the efficiency by calculating the current percent from current flow from emitter to collector. The value of α is typical from 0.9 ~ 0.998.

Biasing: Proper biasing CB configuration in active region by approximation I_C I_E (I_B 0 uA)

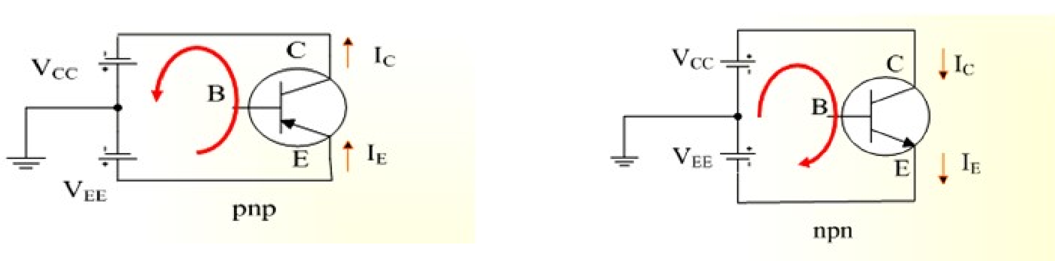


Fig 3.6 CE Configurations

Common-Emitter Configuration

It is called common-emitter configuration since: emitter is common or reference to both input and output terminals. Emitter is usually the terminal closest to or at ground potential. Almost amplifier design is using connection of CE due to the high gain for current and voltage. Two set of characteristics are necessary to describe the behaviour for CE; input (base terminal) and output (collector terminal) parameters. Proper Biasing common-emitter configuration in active region

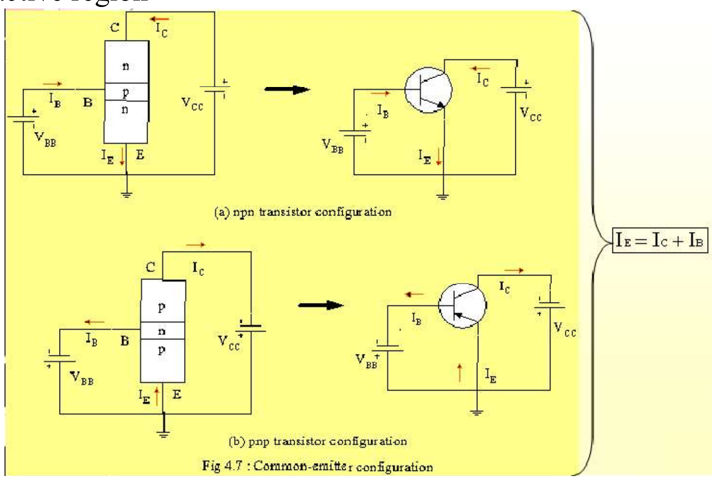


Fig 3.8 CE Configuration

I_B will flow when $V_{BE} > 0.7V$ for silicon and 0.3V for germanium

Before this value I_B is very small and no I_B.

Base-emitter junction is forward bias Increasing V_{CE} will reduce I_B for different values.

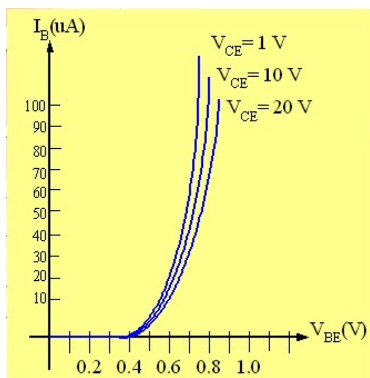


Fig 3.9a Input characteristics for common-emitter npn transistor

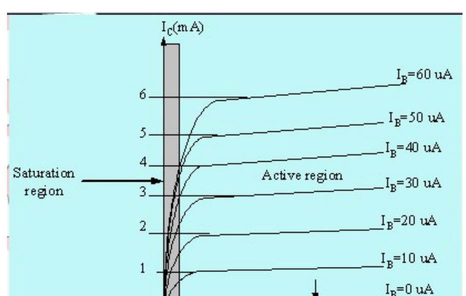


Fig 3.9b Output characteristics for common-emitter npn transistor

For small V_{CE} ($V_{CE} < V_{CESAT}$, I_C increase linearly with increasing of V_{CE}

$V_{CE} > V_{CESAT}$ I_C not totally depends on V_{CE} → constant I_C

I_B(uA) is very small compare to I_C(mA). Small increase in I_B cause big increase in I_C

I_B=0 A → I_{CEO} occur.

Noticing the value when I_C=0A. There is still some value of current flows.

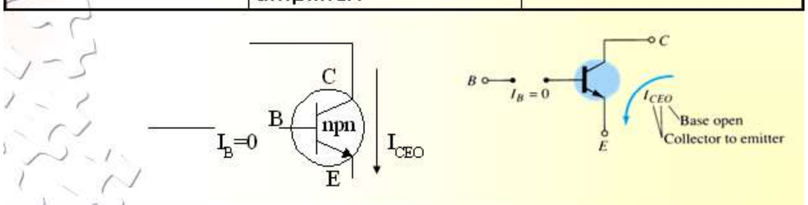
Beta (β) or amplification factor

The ratio of dc collector current (I_C) to the dc base current (I_B) is dc beta (dc) which is dc current gain where I_C and I_B are determined at a particular operating point, Q-point (quiescent point). It's defined by the following equation:

$$30 < \beta_{dc} < 300 \rightarrow 2N3904$$

On data sheet, $\beta_{dc}=h_{fe}$ with h is derived from ac hybrid equivalent circuit. FE is derived from forward current amplification and common-emitter configuration respectively.

Active region	Saturation region	Cut-off region
• B-E junction is forward bias • C-B junction is reverse bias • can be employed for voltage, current and power amplification	• B-E and C-B junction is forward bias, thus the values of I_B and I_C is too big. • The value of V_{CE} is so small. • Suitable region when the transistor as a logic switch. • NOT and avoid this region when the transistor as an amplifier.	• region below I_B=0μA is to be avoided if an undistorted o/p signal is required • B-E junction and C-B junction is reverse bias • I_B=0, I_C not zero, during this condition I_C=I_{CEO} where is this current flow when B-E is reverse bias.



3.7 COMMON – COLLECTOR CONFIGURATION

It is also called emitter-follower (EF). It is called common-emitter configuration since both the signal source and the load share the collector terminal as a common connection point. The output voltage is obtained at emitter terminal. The input characteristic of common-collector configuration is similar with common-emitter configuration. Common-collector circuit configuration is provided with the load resistor connected from emitter to ground. It is used primarily for impedance matching purpose since it has high input impedance and low output impedance.

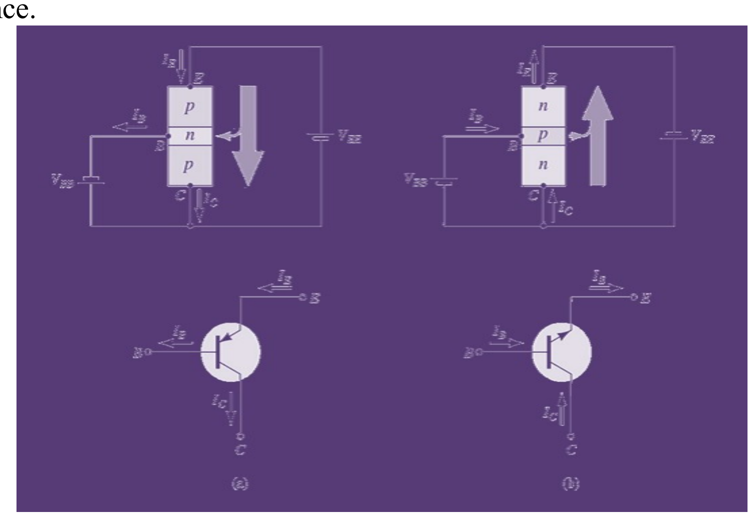


Fig 3.10 CC Configuration

For the common-collector configuration, the output characteristics are a plot of I_E vs V_{CE} for a range of values of I_B.

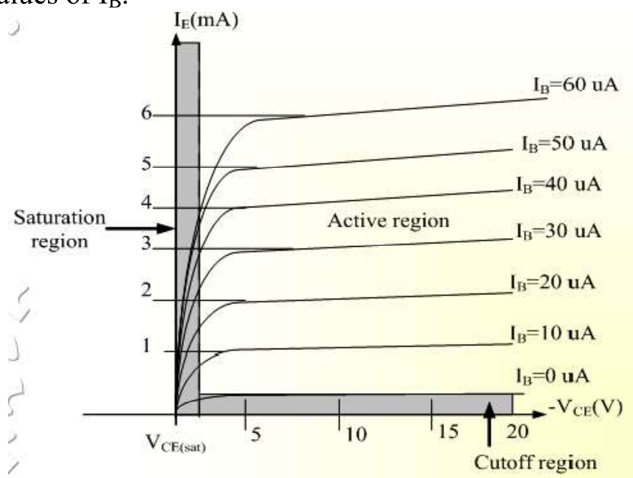


Fig 3.11 Output Characteristics of CC Configuration for npn Transistor

Common Base Configuration

This configuration is also called grounded base configuration. In this configuration the input signal is applied between emitter and base while the output is taken from collector and base. As base is common to input and output circuits, hence the name common base configuration. Fig.3.12 (a) shows the common base NPN transistor circuit.

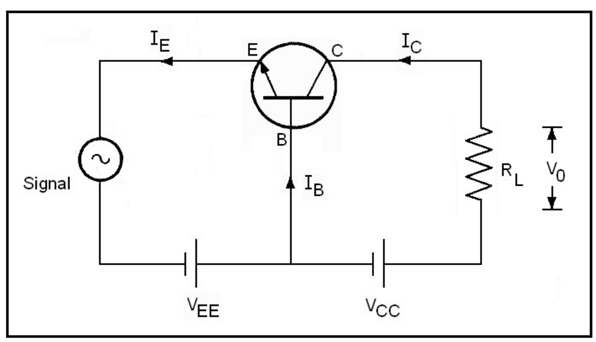


Fig.3.12 (a)

Current Amplification factor (α)

When no signal is applied, the ratio of the collector current to the emitter current is called d.c alpha (α_{dc}) of a transistor.

$$\therefore \qquad \alpha_{dc} = \frac{I_C}{I_E}$$

If we write α_{dc} simply by α, then

$$\alpha = \frac{I_C}{I_E} \tag{1}$$

When signal is applied, the ratio of change in collector current to the change in emitter current at constant collector-base voltage is defined as current amplification factor α_{ac}.

$$\therefore \alpha_{dc} = \frac{\Delta I_C}{\Delta I_E}\Big|_{V_{CB}=\text{constant}}$$

For all physical purposes, $\alpha_{dc} = \alpha_{ac} = \alpha$ and practical values in commercial transistors range from 0.95 to 0.995.

Leakage Current in CB Configuration (I_{CBO})

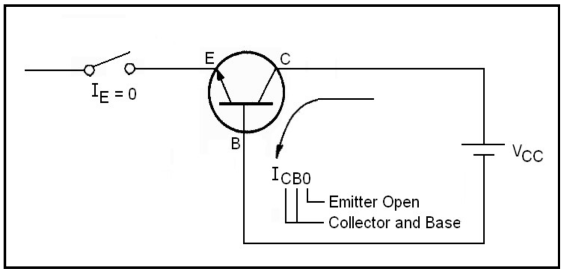


Fig.3.12 (b)

When emitter is open circuited, $I_E = 0$ in CB configuration. In such condition the collector-base junction act as a reverse biased diode and hence a small leakage current flow between the collector and base as shown in fig.3.12(b) The leakage current is known as collector to base leakage current with emitter open and is abbreviated as I_{CBO}.

Expression for Collector Current (I_C)

The total collector current in a common base transistor has the following two components:

1. The part of emitter current which reaches the collector. Its value is αI_E and is due to majority carriers.
2. The leakage current I_{CBO}, produced by the movement of minority carriers across the collector-base junction when reverse biased.

$\therefore$ Total collector current, $I_C = \alpha I_E + I_{leakage} = \alpha I_E + I_{CBO}$

Common Emitter Configuration (CE)

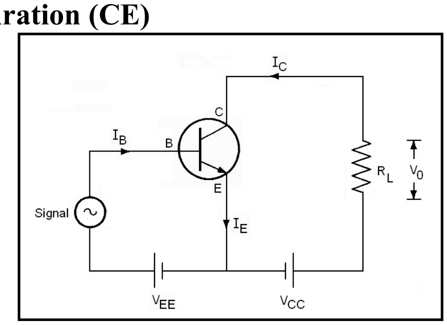


Fig. 3.13(a)

This configuration is also called grounded emitter configuration. In this configuration, the input signal is applied between base and emitter and the output is taken from collector and emitter. As emitter is common to both input and output circuits, hence the name common emitter configuration. Fig.3.13 (a) shows the common-emitter NPN transistor circuit.

Current Amplification factor (β)

When no signal is applied, the ratio of collector current to the base current is called d.c beta (β_{dc}) of transistor.

$$\therefore \qquad \beta_{dc} = \frac{I_C}{I_B}$$

If we write β_{dc} simply by β, then

$$\therefore \beta = \frac{I_C}{I_B} \qquad (5)$$

When signal is applied, the ratio of change in collector current to the change in base current at constant collector-emitter voltage is defined as base current amplification factor β_{ac}.

$$\therefore \beta_{ac} = \frac{\Delta I_C}{\Delta I_B}\bigg|_{V_{CE}=\text{constant}} \qquad (6)$$

For all physical purposes, $\beta_{dc} = \beta_{ac} = \beta$

Almost in all transistors, the base current is less than 2% of the emitter current. Due to this fact, β is generally greater than 20. Usually, β ranges from 20 to 500. Hence, this configuration is frequently used when appreciable current gain as well as voltage gain is required.

Relation between α and β

We know that emitter current (I_E) of a transistor is the sum of its base current (I_B) and collector current (I_C) i.e.

$$I_E = I_B + I_C$$

Dividing the above equation on both sides by I_C,

$$\frac{I_E}{I_C} = \frac{I_E}{I_C} + 1$$

$$\text{Since} \quad \alpha = \frac{I_C}{I_E} \text{ and } \beta = \frac{I_C}{I_B}$$

$$\therefore \frac{1}{\alpha} = \frac{1}{\beta} + 1$$

$$\frac{1}{\alpha} = \frac{1+\beta}{\beta}$$

$$\therefore \alpha = \frac{\beta}{1+\beta}$$

The above expression may be written as

$$\alpha(1+\beta) = \beta$$

$$\alpha + \alpha\beta = \beta$$

$$\beta(1-\alpha) = \alpha$$

$$\therefore \beta = \frac{\alpha}{1-\alpha}$$

Leakage Current in CE Configuration (CE)

When base is open circuited, $I_B = 0$ in CE configuration. In such condition a small leakage current flow between the collector and emitter as shown in figure 3.13(b). The leakage current is known as collector to emitter leakage current with base open and is abbreviated as I_{CEO}.

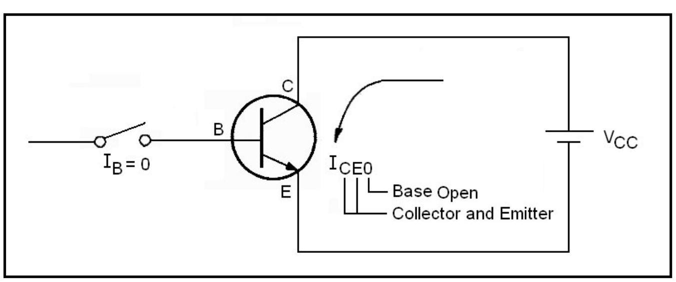


Fig. 3.13(b)

Expression for Collector Current (I_C)

We have seen that in CB configuration I_E is the input current and I_C is the output current. These currents are related through equations (1) and (2).

$$I_E = I_B + I_C \quad (1)$$

$$I_C = \alpha I_E + I_{CBO} \quad (2)$$

To obtain the relation between output current (I_C) and input current (I_B), we simply substitute the equation (1) into equation (2), we get,

$$I_C = \alpha(I_B + I_C) + I_{CBO}$$

$$I_C = \alpha I_B + \alpha I_C + I_{CBO}$$

$$I_C(1-\alpha) = \alpha I_B + I_{CBO}$$

$$\therefore I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO} \quad (3)$$

In this equation, I_C is given in terms of I_B. The equation can be simplified by defining.

$$\beta = \frac{\alpha}{1-\alpha} \quad \text{and} \quad 1+\beta = \frac{1}{1-\alpha}$$

$$I_C = \beta I_B + (1+\beta) I_{CBO}$$

Thus in CE configuration the leakage current (I_{CEO}) is $(1+\beta)$ times the leakage current in CB configuration (I_{CBO}).

$$\therefore I_C = \beta I_B + I_{CEO}$$

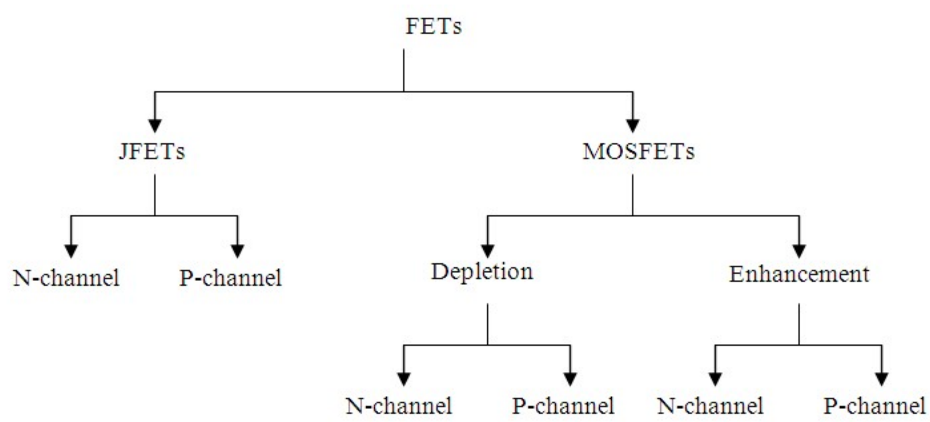
This is the required expression for collector current in CE configuration.

Field Effect Transistor (FET)

Introduction

The field effect transistor (FET) is a three terminal semiconductor device in which the current is controlled by an applied electric field. It is also called a uni-polar transistor because the conduction or operation of FET depends only the majority carriers (i.e. either electrons or holes). **Types of FET's**

The FETs are broadly classified into two types as follows:



FET : Field Effect Transistor

JFET : Junction Field Effect Transistor

MOSFET or IGFET : Metal Oxide Semiconductor Field Effect Transistor (or) Insulated Gate Field Effect Transistor

Construction and Principle of Operation of JFET

A FET consists of N-type or P-type silicon bar containing two PN-junctions at the sides as shown in fig.3.14 (a) & (b). If the bar is N-type then it is named as N-channel FET and if the bar is P-type, then it is named as P-channel FET. The structure of N-channel FET and P-channel FETs are shown in fig.3.14. The circuit symbols employed for N-channel and P-channel FETs are also shown in fig.3.14.

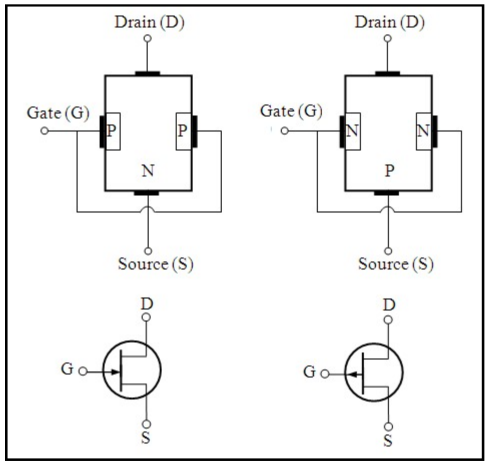


Fig. 3.14(a) Fig.3.14 (b)

Construction of N-channel FET

For the fabrication of N-channel FET, a narrow bar of N-type semiconductor material is taken. On the opposite sides of its middle part, two heavily doped P-type regions are diffused. The two PN-junctions are formed in the bar. These junctions form two PN-diodes and the area between two P-regions is known as channel. The two P-regions are connected to a common lead which is called gate terminal. Ohmic contacts are made at the two ends of N-type semiconductor bar. One lead is called as source terminal S and the other lead is called as drain terminal D. The source and drain may be interchanged. Hence FET is a three terminal device whose terminals are source, drain and gate.

The FET has the following notations:

1. **Source(S):** The source S is a terminal through which the majority carriers enter the bar (like emitter in BJT).
2. **Drain (D):** The drain D is a terminal through which the majority carriers leave the bar (like collector in BJT).
3. **Gate (G):** It is the terminal which connects the both P-regions in case of N-channel FET and the both N-regions in case of P-channel FET, which controls the carrier flow. It is similar to base in BJT.
4. **Channel:** It is the space between the two gates through which the majority carriers flows from source to drain.

Operation

The connections of N-channel FET to the external batteries is shown in fig.3.14(c) & (d).

Case I: When V_{DS} is applied and V_{GS} =0

When no voltage is applied to gate i.e., $V_{GS} = 0$ and V_{DS} is applied between source and drain. The majority carriers i.e. electrons flow through the N-channel from source to drain. Therefore, the conventional drain current I_D flows through the channel from drain to source. The channel resistance is represented as r_d and r_s as shown in fig. 3.14(c) and its magnitude depends on V_{DS} and V_{GS}.

The drain current I_D produce a voltage drop along the channel. This voltage drop reverse biases the PN-junctions and causes the depletion regions to penetrate into the channel, which is not symmetrical.

It penetrates deeper on to channel near drain and less near source because $V_{rd} >> V_{rs}$. (i.e., the reverse bias is higher near drain than compared to source).

Case II: When V_{GS} is applied $V_{DS} = 0$

Consider an N-channel JFET is shown in the fig.3.14 (d). Here the P-type gate and N-type channel constitute PN-junction. In this case the PN-junctions are reverse biased and hence the thickness of the depletion regions increases. As V_{GS} is increased, the reverse bias across the junction increases. Hence the thickness of the depletion regions in the channel will increase till the two depletion regions make contact with each other. In this condition the channel is said to be cut-off. The value of V_{GS} which cut-off the channel is called the cut-off voltage V_{GS} (off).

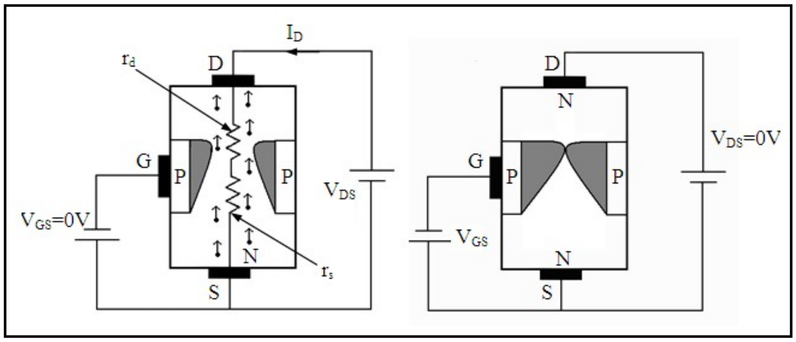


Fig. 3.14(c) Fig.3.14 (d)

Case III: When V_{DS} and V_{GS} are applied

When voltage is applied between the drain and source with a battery V_{DS}, the electrons flow from source to drain through the narrow channel existing between the depletion regions. This constitutes the drain current (I_D), its conventional direction is indicated from drain to source (fig.3.14(c)).

The value of drain current is maximum, when no external voltage is applied between the gate and source (i.e., V_{GS}=0) and is designated by symbol I_{DSS}.

When a reverse voltage V_{GS} is applied between the gate and source terminal, the width of the depletion layer is increased, which in turn reduces the width of the conducting channel there by increasing the resistance of the bar. Hence the current from source to drain decreases.

If the reverse voltage on the gate is decreased the width of the depletion layer decreases which in turn increases the width of conducting channel. Thus the current from source to drain is controlled by the potential or electric field applied on the gate. Hence the device is termed as field effect transistor (FET).

JFET Characteristics

Drain Characteristics of JFET

The curves shows the relationship between the drain current I_D and drain to source voltage V_{DS} for different values of V_{GS} are called drain characteristic of JFET.

Fig.3.15 (a) shows the experimental setup required to plot these characteristics. First adjust the gate source voltage to some suitable value. Then increase the drain to source voltage in small suitable value at each step and record the corresponding values of drain current.

Plot a graph with drain to source voltage (V_{DS}) along the horizontal axis and the current (I_D) along vertical axis, we shall obtain a curve as shown in fig.3.15 (b).

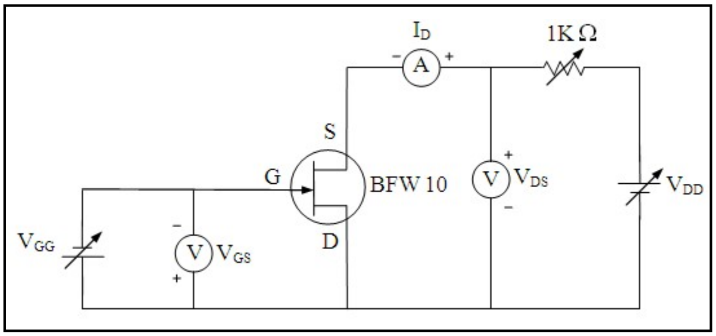


Fig.3.15(a)

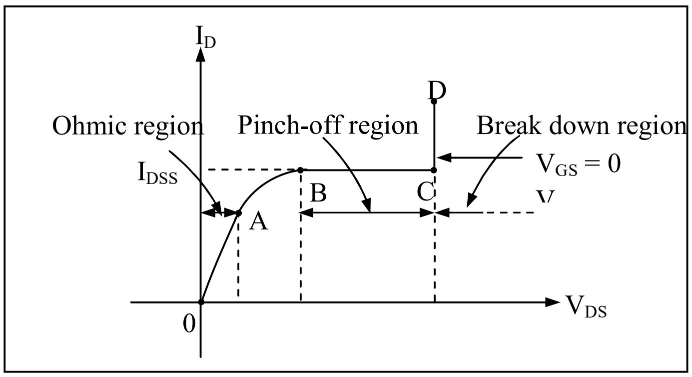


Fig.3.15(b)

It can be sub divided into following four regions:

1. Ohmic region OA
2. Curve AB
3. Pinch-off region
4. Break down region

1. **Ohmic region OA:** In this region, the drain current I_D increases linearly with V_{DS} following ohms law. It means that FET behaves like an ordinary resistor till point A called knee point is reached.
2. **Curve AB:** In this region, I_D increases at inverse square law rate up to point B which is called pinch-off point. The drain to source voltage V_{DS} corresponding to point B is called pinch-off voltage (V_P).
3. **Pinch-off region:** This region is shown by the curve BC in fig.3.15(b). It is also called saturation region or constant current region. In this region, drain current remains constant at its maximum value.

*Note:

a) The drain current in the pinch-off region depends upon the gate to source voltage and is given by the relation,

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

b) This relation is known as Shockley's equation.

c) The pinch-off region is the normal operating region of JFET, when used as an amplifier.

4. **Break down region:** This region is shown by the curve CD in fig. 4.2(b). In this region, the drain current increase rapidly as the drain to source voltage is increased. It is because of the breakdown of gate to source junction due to avalanche effect. The drain to source voltage corresponding to point C is called breakdown voltage.

Transfer Characteristics of JFET

1. These curves shows the relationship between drain current (I_D) and gate to source voltage (V_{GS}) for different values of drain to source (V_{DS}) voltage.

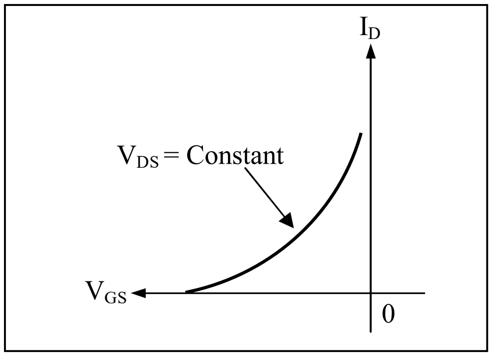


Fig.3.15(c)

2. These transfer characteristics curves are obtained by using the circuit shown in fig.3.15(c). First adjust the drain to source voltage to some suitable value. Then increase the gate to source voltage in small suitable value at each step and record the corresponding values of drain current at each step.
3. Plot a graph with gate to source voltage (V_{GS}) along the horizontal axis and the current (I_D) along the vertical axis, we shall obtain a curve as shown in the fig.3.15(c).
4. The transfer characteristic follow the equation,

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_p}\right)^2$$

5. From the above equation, it is clear that when $V_{GS} = 0$, $I_D = I_{DSS}$ and when $V_{GS} = V_P$,

$$I_D = 0.$$

JFET Parameters

A FET has certain parameters which determine its performance in a circuit. These parameters can be obtained from its two characteristics. The main parameters of a JFET when connected in common source mode are:

a) A.C. drain resistance (r_d)
b) Trans-conductance (g_m)
c) Amplification factor (μ)

A.C. Drain Resistance (r_d)

It is the a.c. resistance between drain and source terminals when JFET operates in the pinch–off region. Therefore, it is defined as the ratio of the change in drain to source voltage (V_{DS}) to the change in drain current (I_D) at constant gate to source voltage (V_{GS}).

$$\therefore \qquad r_d = \left.\frac{\text{Change in } V_{DS}}{\text{Change in } I_D}\right|_{V_{GS}=\text{Constant}}$$

$$\text{or} \qquad r_d = \left(\frac{\Delta V_{DS}}{\Delta I_D}\right)_{V_{GS}=\text{Constant}} \qquad \ldots(1)$$

It is also called dynamic drain resistance. It is measured in ohms. Typically r_d is about 400 KΩ.

Trans-conductance (g_m)

The control that the gate voltage has over the drain current is measured by trans-conductance. It is defined as the ratio of change in drain current (I_D) to the change in gate to source voltage at constant drain to source voltage (V_{DS}).

$$\therefore \qquad g_m = \left.\frac{\text{Change in } I_D}{\text{Change in } V_{DS}}\right|_{V_{DS}=\text{Constant}}$$

$$\text{Or} \qquad g_m = \left.\frac{\Delta I_D}{\Delta V_{GS}}\right|_{V_{DS}=\text{Constant}} \qquad \ldots (2)$$

Its unit is Siemens (S) which was earlier called mho or A/V. it is unit also called forward trans-conductance. Typically g_m ranges from 150 μS to 250 μS.

Amplification factor (μ)

It is defined as the ratio of change in drain to source voltage (V_{DS}) to the change in gate to source voltage (V_{GS}) at constant drain current (I_D).

$$\therefore \mu_m = \left.\frac{\text{Change in } V_{DS}}{\text{Change in } V_{GS}}\right|_{I_D=\text{Constant}}$$

$$\text{or} \qquad \mu_m = \left(\frac{\Delta V_{DS}}{\Delta V_{GS}}\right)_{I_D=\text{Constant}} \qquad \ldots(3)$$

Since μ is the ratio of two voltages, it has no unit. The amplification factor of a FET can be as high as 100.

Relation among FET Parameters

From eq. (1), (2) and (3) it can be seen that,

$$\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}} = \frac{\Delta V_{GS}}{\Delta V_{GS}}\frac{\Delta I_D}{\Delta I_D}$$

$$\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}} = \frac{\Delta V_{GS}}{\Delta I_D} \times \frac{\Delta I_D}{\Delta V_{GS}}$$

$$\mu = r_d\, g_m$$

Advantages and Disadvantages of FET over BJT

Its advantages over BJT are as follows:

1. It has very high input impedance.
2. It produces low noise than BJT.
3. It has negative temperature coefficient of resistance. This avoids the risk of thermal run away.
4. It has no offset voltage at zero drain current and hence it acts as an excellent signal chopper.
5. Small size, longer life and high efficiency.
6. It has better thermal stability.

Disadvantages of FET

The following are the disadvantages of FET:

1. Less gain for a given bandwidth, i.e. small gain band width product.
2. Smaller power ratings.
3. Switching speed is lower.

Differences between JFET and BJT

S.No.	Field Effect Transistor (FET)	Bipolar Junction Transistor (BJT)
1.	The current flowing is due to only majority carriers.	The current flowing is due to both majority and minority carriers
2.	It is a uni-polar device.	It is a bipolar device.
3.	Its input impedance is high.	Its input impedance is low.
4.	It is a voltage controlled device.	It is a current controlled device.
5.	It has better thermal stability.	It has poor thermal stability.
6.	It has low voltage gain.	It has high voltage gain.
7.	No thermal runaway.	There is thermal runaway.
8.	It is less noisy than a BJT and vacuum tube.	Noisier than a FET.
9.	Cost is high.	Cost is low.
10.	Its power gain is more at audio frequencies.	Its power gain is less at audio frequencies.
11.	It is much simpler to fabricate and occupies a less space on IC chip.	It is comparatively difficult to fabricate and occupies more space on IC chip.
12.	Source and Drain terminals are interchangeable.	Emitter and collector terminals are not interchangeable.

Applications of FETs

1. The main advantages of the unipolar transistor, or FET, are the very high input impedance, no offset voltage, and low noise. For these reasons a FET is most useful in a low level high input impedance circuit, such as a signal chopper or the first stage of a unipolar-bipolar cascade combination.
2. FET is also used as a voltage variable resistor (VVR) or voltage dependent resistor (VDR).
3. On account of being square law device, FETs are frequently used in the tuners of radio and TV receivers.
4. In a FET, since the gate draws no current, it has very high input impedance and hence it is suitable for being used in electronic voltmeters, which are popularly called FETs meter.
5. Because of the high input impedance and low output impedance, a FET acts as an excellent buffer amplifier.

Metal Oxide Semiconductor Field Effect Transistor (MOSFET)

The input impedance of a JFET is not high because gate to source junction is reverse biased and very small reverse current flows. Also, JFET can be operated in depletion mode only. Thus, the signal handling capacity of an amplifier using JFET is limited and gain per stage is less. To overcome the above limitations, fabrication of FET is modified.

Fig.3.16 (a) shows the constructional details of N-channel MOSFET. It is similar to JFET except with the following modifications:

1. There is only a single P-region. This region is called substrate.
2. A thin layer of metal oxide (usually silicon dioxide) is deposited over the left side of the channel. A metallic gate is deposited over the oxide layer.

As silicon dioxide (SiO_2) is an insulator, therefore the gate current becomes very small, resulting in very high input impedance lying in the range $10^{10}\Omega$ to $10^{15}\ \Omega$. The gate can also be forward biased. Thus MOSFETs may be operated in either enhancement mode or depletion mode. Signal handling capacity improves greatly.

A parallel plate capacitor is formed with the metal area of the gate and the semiconductor channel acting as the electrodes and the oxide layer as the dielectric in between the electrodes. Thus the gate has been insulted by means of SiO_2 layer. For this reason, MOSFET is sometimes called insulated gate FET (IGFET).

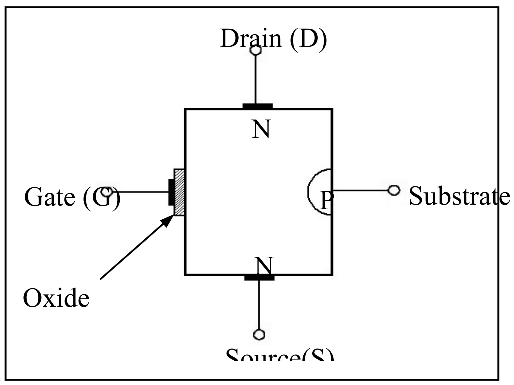
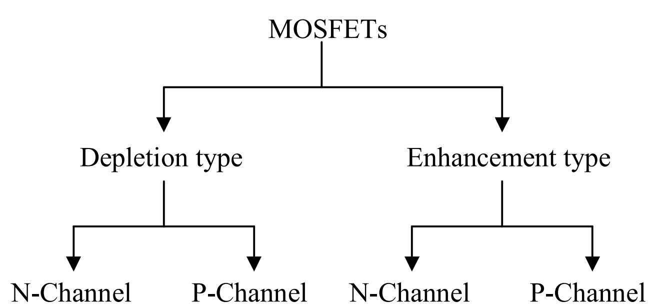


Fig.3.16

The MOSFETs are broadly classified into two types as follows:



MOSFET: Metal Oxide Semiconductor Field Effect Transistor

Depletion type MOSFET

Construction of N-channel Depletion type MOSFET

The fig.3.17 (a) shows the basic construction of N-channel depletion type MOSFET. Two highly doped N^+ regions are diffused into a lightly doped P-type substrate. These two highly doped N^+ regions acts as source and drain. In some cases substrate is internally connected to the source terminal.

*Note: As there is no direct electrical connection between the gate terminal and the channel of a MOSFET, increasing the input impedance of the device

The source and drain terminals are connected through metallic contacts to N^+ doped regions linked by an N-channel as shown in fig.3.17(a). A thin layer of metal aluminium is deposited over the layer of SiO_2. This layer covers the entire channel region between source and drain and it constitutes the gate.

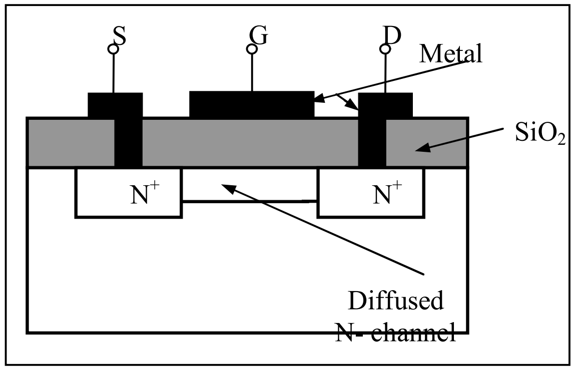


Fig.3.17 (a)

Working of N-channel Depletion type MOSFET

Case I: When V_{GS} = 0 V and V_{DS} = +Ve

Let us consider that V_{GS} = 0 V and the drain D at a positive potential with respect to the source S, the majority carriers i.e. electrons flow through the N-channel from source(S) to drain(D). The behavior is similar to that of the JFET and the saturation current under these conditions is called I_{DSS} (drain current with source short circuited to gate).

Case II: When V_{GS} = - Ve and V_{DS} = + Ve {Depletion mode}

When a negative voltage is applied to the gate, the conduction electrons are repelled from the channel and holes are attracted from P-type substrate. This initiates recombination of repelled electrons and attracted holes.

The level of recombination between electrons and holes depends on the magnitude of the negative voltage applied to the gate. This recombination reduces the number of free electrons in the N-channel for the conduction, reducing the drain current. Thus the level of drain current will reduce with increasing negative bias for V_{GS} as shown in the transfer characteristics of depletion type MOSFET (fig.3.17(c)).

*Note: In fact, too much negative gate voltage can cut off the channel. Hence with negative gate voltage, a DEMOSFET behaves like a FET.

Case III: When V_{GS} = +Ve and V_{DS} = +Ve {Enhancement mode}

For positive values of V_{GS} the positive gate will draw additional electrons from the P-type substrate. These electrons are added to those already existing in the channel. This increased number of electrons increases or enhances the conductivity of the channel.

*Note:

1. The device operates in depletion mode, when the gate voltage is negative.
2. The device operates in enhancement mode, when the gate voltage is positive.

Characteristics of N-channel Depletion type MOSFET

Drain Characteristics

The fig.3.17(b) shows the drain characteristics for the N-channel depletion type MOSFET.

These curves are plotted for both negative and positive values of gate to source voltage (V_{GS}). The curves shown above the $V_{GS} = 0$ have a positive value where as those below it have a negative value of V_{GS}.

When V_{GS} is zero and negative, the MOSFET operates in the depletion mode. On the other hand, if V_{GS} is zero and positive, the MOSFET operates in the enhancement mode. The only difference between the JFET and the depletion MOSFET is that JFET does not operate for positive values of gate to source voltage (V_{GS}).

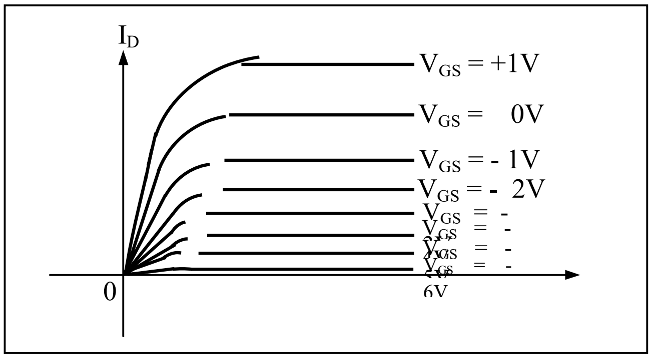


Fig.3.17 (b)

Transfer Characteristics

The transfer characteristics for a N-channel MOSFET is shown in fig 3.17(c) The transfer characteristics give the variation of the drain current I_D with the gate to source voltage V_{GS} for a fixed value of V_{DS}. On the left hand side of curve is the depletion mode, where V_{GS} is negative. On the right hand side of curve is the enhancement mode, where V_{GS} is positive.

*Note:It may be noted that even if $V_{GS} = 0$, the device has a drain current equal to I_{DSS}. Due to this fact it is called normally ON MOSFET.

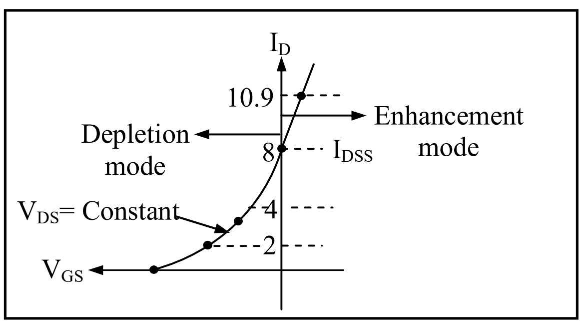


Fig. 3.17(c)

Enhancement type MOSFET

Construction

The fig.3.18 (a) shows the basic construction of N-channel enhancement type MOSFET. Two highly doped N^+ regions are diffused into a lightly doped P-type substrate. These two highly doped N^+ regions acts as the source and drain. A thin layer of SiO_2 is grown over the surface of the structure. Holes are cut into this SiO_2 layer for making contact with source and drain region. A thin layer of metal aluminium is formed over the layer of SiO_2, and it constitutes the gate

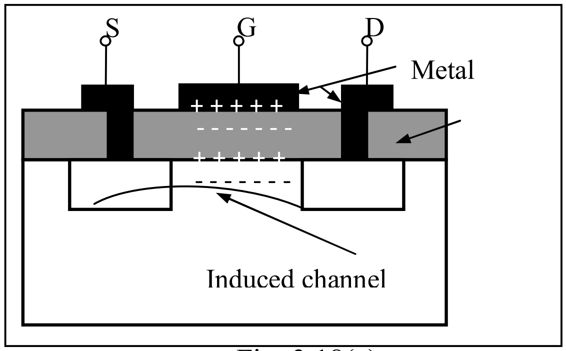


Fig. 3.18(a)

*Note:

1. It differs in construction from the depletion type MOSFET in that it has no physical channel.
2. This type of MOSFET operates only in the enhancement mode and has no depletion mode.

Working

Case I: V_{GS} = 0 and V_{DS} = +Ve

If the gate is grounded (V_{GS}=0) and some voltage is applied to the drain $(V_{DS} = +Ve)$, the supply tries to draw free electrons (if any) towards the drain. However, the P-substrate has very few thermally generated free electrons. As a result, this type of MOSFET is OFF when $V_{GS} = 0$. this behaviour is different from that of the depletion type where I_{DSS} flows.

Case II: V_{GS} = +Ve and V_{DS} = +Ve

When a positive potential is applied to the gate, electrons from the substrate are attracted to the region near the SiO_2 layer. When the gate potential is sufficiently positive, sufficient number of electrons is drawn into that region and converts it into an N-type region (i.e., the P-type material is inverted to form an N-type channel). Thus an N-type channel is induced between the drain and the source.

At a particular value of V_{GS} there is a measurable current flow between drain and source. This value of V_{GS} is called threshold voltage denoted by V_T.

Thus we can say that in an enhancement type N-channel MOSFET, the conductivity of the channel is enhanced by increasing the gate to source voltage and thus pulling more electrons in to the channel.

*Note:

1. For any voltage below the threshold value, there is no channel.
2. Typical values of V_T are in the range of 1-3 V.
3. The construction of the P-channel is exactly the reverse of the N-channel.

Drain Characteristics

Fig.3.18 (b) shows the drain characteristics of an N-channel enhancement type MOSFET. Looking at fig.3.18 (b) we can say that as V_{GS} increases beyond the threshold level, the density of free carriers (electrons) in the induced channel increases, increasing the drain current. However, at some point of V_{DS}, for constant V_{GS}, the drain current reaches a saturation level. The levelling off of I_D is due to a pinch-off process, is as described earlier for the JFET.

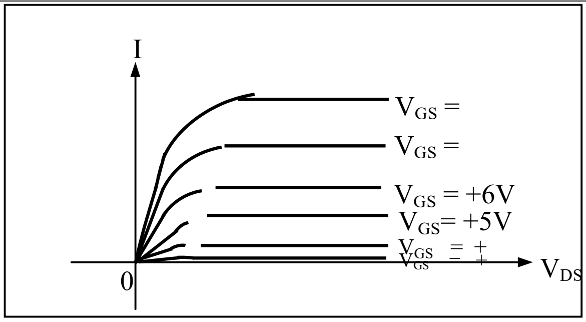


Fig. 3.18(b)

Transfer Characteristics

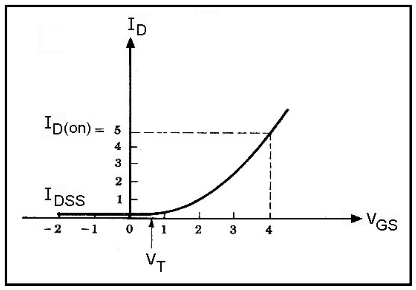


Fig.3.18(c)

Fig.3.18(c) shows the transfer characteristic for N-channel enhancement type MOSFET. This characteristic is quite different from characteristic that we obtained for JFET and depletion type MOSFET. For N-channel enhancement type MOSFET, V_{GS} is in the positive region. The drain current does not start rising until $V_{GS} = V_T$.

Circuit Symbols of MOSFETs

D-MOSFET Circuit Symbols

Fig.3.19 (a) shows graphic symbols for an N and P-channel depletion-type MOSFETs. In the symbol insulation between gate and channel is represented by a space between the gate and other terminals of the symbol. The vertical line represents that the channel is connected between the drain and source and is supported by the substrate (in some cases it is internally shorted to source terminal).

Fig.3.19 (a)

E-MOSFET Circuit Symbols

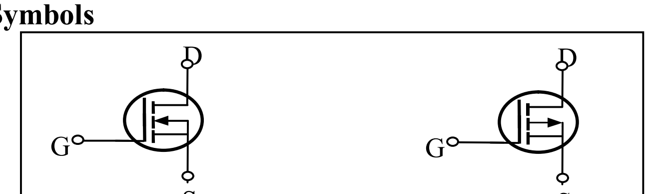


Fig. 3.19 (b)

Fig. 3.19(b) shows circuit symbols for an N and P-channel enhancement type MOSFETs. The dashed line between drain and source represents the fact that a channel does not exists between source and drain under no-bias conditions. It is the only difference between the symbols for the depletion type and enhancement type.

Differences between JFET & MOSFET

Sl.No.	JFET	MOSFET
1.	Input impedance is of the order of $10^8\Omega$.	Input impedance is of the order of 10^{10} to $10^{15}\Omega$.
2.	It is operated only in depletion mode.	The depletion MOSFET can be operated in both depletion mode and enhancement mode.
3.	There are two P-regions in N-channel JFET (or) two N-regions in P-channel JFET.	There is only one P-region in N-channel MOSFET (or) one N-region in P-channel MOSFET.
4.	The channel and gate forms a PN-junction.	The channel and gate forms a parallel a parallel plate capacitor.
5.	Gate is not insulated from channel.	Gate is insulated from channel by a layer of SiO_2.
6.	Gate current is high.	Gate current is low.
7.	Channel exists permanently.	Channel exists permanently in depletion type MOSFET, but not in enhancement type MOSFET
8.	Much easier to fabricate.	Compared to JFETs, MOSFETs are much easier to fabricate.
9.	Conductivity is controlled by the reverse voltage to the gate.	Conductivity is controlled by the electric field induced across an insulating layer deposited on the semiconducting material.
10.	JFETs are widely used in analog circuits.	MOSFETs are widely used in digital circuits.
11.	These are two types of JFETs they are: a) N-channel JFET b) P-channel JFET	These are two types of MOSFETs; they are: a) Depletion type MOSFET b) Enhancement type MOSFET

Applications of MOSFETs

The MOSFETs may be used in any of the circuits covered for JFET, with substrate connected to the source. Because of their high input resistances, the enhancement type MOS devices have been used as micro-resistors in integrated microcircuits.

It is easier to fabricate MOSFET. On account of the advantage of MOSFET, it is widely used than JFET. The enhancement type MOSFET finds wide applications in digital circuitry.

BJT BIASING

Need for Biasing in Amplifier Circuits

In order to operate transistor in the desired region, we have to apply external d.cvoltages of correct polarity and magnitude to the two junctions of the transistor. This is nothing but the biasing of the transistor.

The basic purpose of transistor biasing is to keep the emitter-base junction properly signal. This can be achieved with a battery or associating a circuit with transistor. The latter biasing is known as biasing circuit. It may be noted that transistor biasing is very essential. When we bias a transistor we establish certain current and voltage conditions for the transistor, There conditions are known as operating conditions .

Types of Biasing Circuits

The various methods of biasing a transistor are:

1. Fixed bias (also called base bias)
2. Collector to base bias (also called base bias with collector feedback)
3. Emitter bias (also called base bias with emitter feedback)
4. Voltage divider bias or universal bias or (also called self bias)

Fixed Bias or Base Resistor Method

Fig. 4.5(a) shows an NPN transistor connected in CE configuration with fixed bias. In this method, a high resistance R_B is connected between positive terminal of supply V_{CC} and base of the transistor. Here the required zero signal base current is provided by $+V_{CC}$ and it flows through R_B.

*Note:

1. In fig. 4.5(a) the base-emitter junction is forward biased because the base is positive w.r.t emitter. By a proper selection of R_B the required zero signal base current (and hence $I_C = \beta I_B$) can made to flow.
2. It should be remembered that if the transistor is PNP, then R_B is connected between negative terminal of supply V_{CC} and base of the transistor.

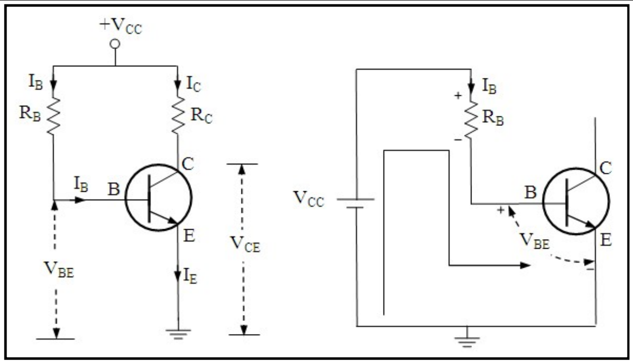


Fig. 4.5(a) Fig. 4.5(b)

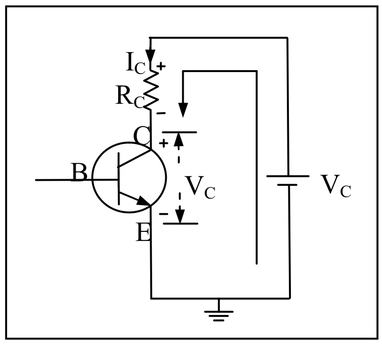


Fig. 4.5(c)

Circuit Analysis

Case I: Base Circuit

Let us consider the base circuit as shown in fig. 4.5(b).

Applying KVL to the base circuit, we get,

$$+V_{CC} - I_B R_B - V_{BE} = 0$$

$$I_B R_B = V_{CC} - V_{BE}$$

$$\therefore \quad I_B = \frac{V_{CC} - V_{BE}}{R_B} \quad \ldots(1)$$

The supply voltage V_{CC} is of fixed value. Once the resistance R_B is selected, I_B is also fixed hence this circuit is called fixed bias circuit.

Case II: Collector Circuit

Let us consider the collector circuit as shown in fig. 4.5(c). Applying KVL to the collector circuit, we get,

$$V_{CC} - I_C R_C - V_{CE} = 0$$

$$\therefore \quad V_{CE} = V_{CC} - I_C R_C \quad \ldots(2)$$

$$\therefore \quad I_C R_C = V_{CC} - V_{CE}$$

$$\therefore \quad I_C = \frac{V_{CC} - V_{CE}}{R_C} \quad \ldots(3)$$

Stability factor

The stability factor S is given by, $S = \dfrac{1+\beta}{1-\beta\left(\dfrac{dI_B}{dI_C}\right)}$ … (4)

From equation (1), we have, $I_B = \frac{V_{CC} - V_{BE}}{R_B}$

Differentiating the above equation w.r.t I_C, we get,

$$\frac{dI_B}{dI_C} = 0$$

Substituting this value in equation (4), we get,

$$S = 1 + \beta$$

Thus the stability factor in a fixed bias is $(1+\beta)$. If $\beta = 100$, then S=101. This shows that I_C changes 101 times as much as any change in I_{C0}. Due to the large value of S in a fixed bias, it has poor thermal stability.

Advantages

1. The biasing circuit is very simple as only one resistance R_B is required.
2. It is easy to fix the Q-point anywhere in active region by simply changing the value of R_B.

Disadvantages

1. This method provides poor stabilization. It is because there is no means to stop a self-increase in collector current due to temperature rise and individual variations. For example if β increases due to transistor replacement, then I_C also increases by the same factor as I_B is constant.
2. The stability factor is very high. Therefore, there are strong chances of thermal runaway.

*Note: Due to these disadvantages, this method of biasing is rarely employed.

Potential divider bias or Self bias

A very commonly used biasing arrangement is voltage divider bias. The circuit arrangement is shown in fig. 4.8(a). This is also known as universal bias stabilization circuit. The name voltage-divider is derived from the fact that the resistors R_1 and R_2 form voltage divider across V_{CC}. The emitter resistance R_E provides stabilization. The voltage developed across R_2 forward biases the base-emitter junction. This causes the base current and hence collector current flows in the zero signal conditions.

Circuit Analysis

Method I: **Approximate Analysis**

Let current I_1 flows through R_1. As the base current I_B is very small the current flowing through R_2 can also be taken as I_1. The calculation of collector current I_C is as follows:

The current I_1 flowing through R_1 and R_2 is given by,

$$I_1 = \frac{V_{CC}}{R_1 + R_2}$$

The voltage V_2 developed across R_2 can be determined by applying voltage divider rule.

$$\therefore \qquad V_2 = V_{CC} \frac{R_2}{R_1 + R_2}$$

Case I: **Base Circuit**

Applying KVL to the base circuit, we get,

$$-V_{BE} - V_E + V_2 = 0$$

$$V_E = V_2 - V_{BE} \qquad \ldots(1)$$

$$\therefore\ I_E R_E = V_2 - V_{BE}$$

$$\therefore \qquad I_C = \frac{V_2 - V_{BE}}{R_E} \quad (\because I_E \approx I_C) \qquad \ldots(2)$$

Here I_C is almost independent of transistor parameters and hence good stabilization is achieved

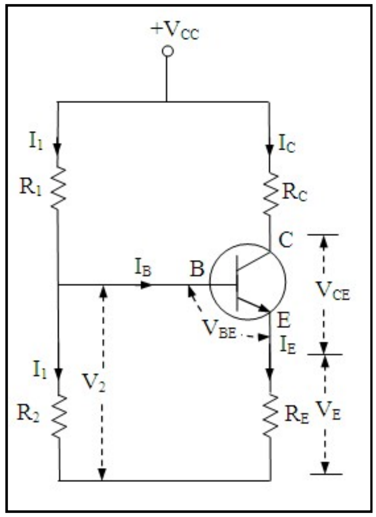


Fig. 4.8(a)

Case II: Collector Circuit

Applying KVL to the collector circuit, we get,

$$+V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

$$\therefore\ V_{CE} = V_{CC} - I_C R_C - I_E R_E$$

$$V_{CE} = V_{CC} - I_C (R_C + R_E) \quad (\because I_E \approx I_C) \qquad \ldots(3)$$

It may be noted that in equations (2) and (3) the β does not appear at all. Therefore the variation of β will have no effect on Q-point. Hence Q-point is independent of beta (β).

*Note: The equation (2) and (3) determines the co-ordinates of Q-point.

Method II: Exact Analysis

Applying Thevenins theorem to the input circuit of fig. 4.8(a).

Step 1: To find the Thevenins equivalent voltage considers the fig. 4.8(b).

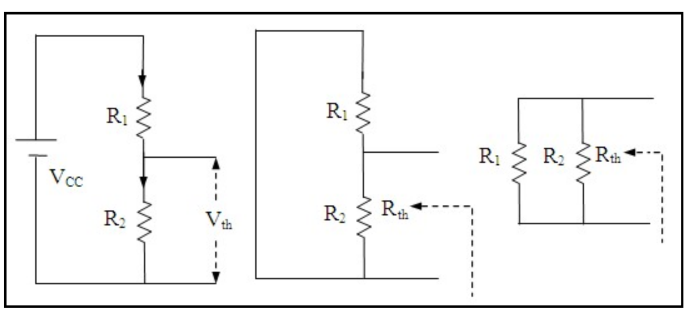


Fig. 4.8(b) Fig. 4.8(c) Fig. 4.8(d)

The voltage across R_2 is the Thevenins equivalent voltage (V_{th}).

$$\therefore \qquad V_{th} = V_{CC}\ \frac{R_2}{R_1 + R_2}$$

Step 2: To find Thevenins equivalent resistance (R_{th}) consider the fig. 4.8(d). Here R_{th} is the parallel combination of R_1 and R_2.

$$\therefore \quad R_{th} = R_1 \| R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

Step 3: Thevenins equivalent circuit of fig. 4.8(a) is shown in fig. 4.8(e).

Case I: Base Circuit

Applying KVL to the base emitter circuit, we get,

$$+V_{th} - I_B R_{th} - V_{BE} - I_E R_E = 0$$

$$V_{th} - I_B R_{th} - V_{BE} - (I_B + I_C) R_E = 0$$

$$I_B (R_{th} + R_E) = (V_{th} - I_C R_E) - V_{BE}$$

$$\therefore \quad I_B = \frac{(V_{th} - I_C R_E) - V_{BE}}{R_{th} + R_E} \quad \ldots(1)$$

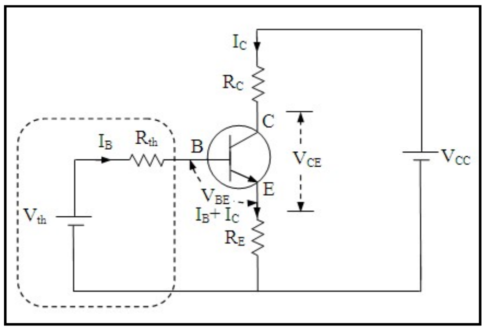


Fig. 4.8(e)

Case II: Collector Circuit

Applying KVL to the emitter collector circuit, we get,

$$+V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

$$\therefore \quad V_{CE} = V_{CC} - I_C (R_C + R_E) \quad \ldots(2)$$

$$\therefore \quad I_C = \frac{V_{CC} - V_{CE}}{R_C + R_E} \quad \ldots(3)$$

Stability factor

The stability factor S is given by, $S = \dfrac{1+\beta}{1 - \beta\left(\dfrac{dI_B}{dI_C}\right)}$ ...(4)

From equation (1), we have, $I_B = \dfrac{(V_{th} - I_C R_E) - V_{BE}}{R_{th} + R_E}$

Differentiating the above equation w.r.t I_C, we get,

$$\frac{dI_B}{dI_C} = \frac{-R_E}{R_{th} + R_E}$$

Substituting the value of $\dfrac{dI_B}{dI_C}$ in equation (4), we get,

$$S = \frac{1+\beta}{1 + \beta\left(\dfrac{R_E}{R_{th} + R_E}\right)}$$

This expression shows that smaller is the value of R_{th}, better is the stability.

Advantages

1. Excellent stabilization.
2. I_C and V_{BE} are independent of β .
3. Increase in temperature will not affect the Q-point.

Disadvantages

1. Circuit is little complicated and need Thevenins theorem to do the calculations.

Comparison of Transistor Configurations

Sl.No	Parameters	Common Base	Common Emitter	Common Collector
1.	Input resistance	Very Low	Low	High
2.	Output resistance	Very high	High	Low
3.	Current gain	Nearly unity	High	High
4.	Voltage gain	High	High	Nearly unity
5.	Power gain	High	Very high	Low
6. 7.	Phase reversal Input current	No I_E	Yes I_B	No I_B
8.	Output current	I_C	I_C	I_E
9.	Input voltage applied between	Emitter & Base	Base & Emitter	Base & Collector
10.	Output voltage taken between	Collector & Base	Collector & Emitter	Emitter & Collector
11.	Current amplification factor	$\alpha = \frac{I_C}{I_E}$	$\beta = \frac{I_C}{I_B}$	$\gamma = \frac{I_E}{I_B}$
12.	Applications	As a input stage multi-stage amplifier	For audio signal amplification	For impedance matching

TWO MARK QUESTION AND ANSWERS

UNIT- I

1. What are the classifications of semiconductors?

The semiconductors are classified as intrinsic and extrinsic semiconductors. A pure semiconductor is called intrinsic semiconductor. A doped semiconductor is called as an extrinsic semiconductor.

2. What is meant by doping?

The process of adding impurities to a semiconductor is known as doping.

3. How the extrinsic Semiconductors are classified?

N-type semiconductor and P-type semiconductor

4. How the n-type semiconductor can be obtained?

The n-type semiconductor can be obtained by adding pentavalent impurities to intrinsic semiconductor. Examples for pentavalent atoms are Arsenic, phosphorous, bismuth and antimony

5. How the p-type semiconductor can be obtained?

The p-type semiconductor can be obtained by adding trivalent impurities to intrinsic semiconductor. Examples for trivalent atoms are boron, indium and gallium.

6. Define Fermi level? And what is Fermi Dirac distribution function?

Fermi level is the energy at which the probability of occupation by an electron is exactly 0.5

$$\mathrm{F(E)} = \frac{1}{1 + e^{(E-E_F)/KT}}$$

7. For Intrinsic semiconductor where the Fermi level lies?

The Fermi level lies in the centre of the forbidden energy band for an intrinsic semiconductor.

8. What is energy band gap of silicon and germanium at 300^0k?

For germanium 0.66 eV; for silicon 1.12eV

9. What is mass action law?

Under equilibrium the product of number of holes and the number of electron is constant and is independent of the amount of donor and acceptor atoms. This relation is known as mass action law and is given by $np=n_i^2$

10. Write an expression for the conductivity of a semiconductor?

The conductivity of a semiconductor is given by $\sigma = (n\mu_n + p\mu_p)$q

11. What is depletion region in PN junction?

The region around the junction from which the mobile charge carriers (electrons and holes) are depleted is called as depletion region. Since this region has immobile ions, which are electrically charged, the depletion region is also known as space charge region.

12. Give the other names of depletion region?

i. Space charge region ii. Transition region

13. What is barrier potential?

The oppositely charged ions present on both sides of PN junction an electric potential is established across the junction even without any external voltage source which is termed as barrier potential.

14. What is meant by biasing a PN junction?

Connecting a PN junction to an external voltage source is biasing a PN junction.

15. What is forward bias and reverse bias in a PN junction?

When positive terminal of the external supply is connected to P region and negative terminal to N region, the PN junction is said to be forward biased. Under forward biased condition the PN region offers a very low resistance and a large amount of current flows through it.

16. What is Reverse saturation current?

The current due to the minority carriers in reverse bias is said to be reverse saturation current. This current is independent of the value of the reverse bias voltage.

17. Why contact differences of potential exist in PN junction?

When a PN junction is formed by placing a p-type and n-type material in intimate contact, the Fermi level throughout the newly formed specimen is not constant at equilibrium. There will be transfer of electron and energy until Fermi levels in the two sides did line up. But the valence and conduction band in p side cannot be at the same level as in n side .this shift in energy level results in contact difference of potential.

18. What is the static resistance of a diode?

Static resistance R of a diode can be defined as the ratio of voltage V across the diode to the current flowing through the diode.

$$R = V/ I$$

Where, R - Static resistance of a diode,
V - Voltage across the diode
I - current across the diode

19. Define dynamic resistance.

Dynamic resistance of a diode can be defined as the ratio of change in voltage across the diode to the change in current through the diode.

$$r = V / I$$

Where r - Dynamic resistance of a diode,
V - Change in voltage across the diode
I - change in current through the diode

20. What is an ideal diode?

An ideal diode is one which offers zero resistance when forward biased and infinite resistance when reverse

21. Define knee/cut-in/threshold voltage of a PN diode.

It is the forward voltage applied across the PN diode below which practically no current flows Biased.

22. What is the effect of junction temperature on cut-in voltage of a PN diode?

Cut-in voltage of a PN diode decreases as junction temperature increases.

23. What is the effect of junction temperature on forward current and reverse current of a PN diode?

For the same forward voltage, the forward current of a PN diode increases and reverse saturation current increases with increase in junction temperature.

24. Define transition capacitance of a diode.

Transition Capacitance (CT) or Space-charge Capacitance: When a PN-Junction is reverse biased, the depletion region acts like an insulator or as a dielectric. The P- and N-regions on either side have low resistance and act as the plates. Hence it is similar to a parallel-plate capacitor. This junction capacitance is called transition or space-charge capacitance

25. Differentiate avalanche and Zener breakdowns.

Zener break down	Avalanche breakdown
Breakdown occurs due to heavily doped junction and applied strong electric field	Breakdown occurs due to avalanche multiplication between thermally generated ions
Doping level is high	Doping level is low
Breakdown occurs at lower voltage compared to avalanche breakdown	Break down occurs at higher voltage

26. Differentiate Drift and Diffusion currents

Drift current	Diffusion current
It is developed due to potential gradient	It is developed due to charge concentration gradient
This phenomenon is found both in metals and semiconductors	This is found only in semiconductors

27. Define diffusion capacitance of a diode.

Diffusion or Storage Capacitance (CD): This capacitive effect is present when the junction is forward-biased. It is called diffusion capacitance due to the time delay in minority charges across the junction by diffusion process. Due to this fact, this capacitance cannot be identified in terms of a dielectric and plates. It varies directly with forward current. When a forward-biased PN-junction is suddenly reversed biased, a reverse current flow which is large initially, but gradually decreases to the level of saturation current, I_0.

28. State the principle of operation of an LED.

When a free electron from the higher energy level gets recombined with the hole, it gives out the light output. Here, in case of LEDs, the supply of higher level electrons is provided by the battery connection.

29. State any four advantages of LED.

They are small in size.

i. Light in weight.
ii. Mechanically rugged.
iii. Low operating temperature.
iv. Switch on time is very small.
v. Available in different colours.
vi. They have longer life compared to lamps.
vii. Linearity is better.
viii. Compatible with ICs
ix. Low cost

30. State some disadvantages of LED.

i. Output power gets affected by the temperature radiation.
ii. Quantum efficiency is low.
iii. Gets damaged due to over –voltage and over-current.

UNIT- I(A)

1. What are the advantages of bridge rectifier over center tapped counterpart?

- The ripple factor and efficiency are same as full wave rectifier.
- The bulky centre tapped transformer is not required.

2. Define and explain peak inverse voltage (PIV)?

Peak inverse voltage is the maximum reverse voltage that can be applied to the PN junction without damage to the junction. If the reverse voltage across the junction exceeds to its peak inverse voltage, the junction may be destroyed due to excessive heat.

3. Define ripple factor?

Ripple factor can be defined as the variation of the amplitude of DC (Direct current) due to improper filtering of AC power supply.

4. Define TUF of a rectifier.

Most of the rectifier circuits make use of transformer whose secondary feeds the AC power. The transformer rating is necessary to design a power supply. Transformer utilization factor (TF) is defined as the ratio of DC power delivered to the load to the AC power rating of transformer secondary.

5. Give the advantages and disadvantages of HWR.

Half Wave Rectifier (HWR)

Advantages

- Simple circuit.
- Low cost.

Disadvantages.

- Rectification efficiency is low (40.6%).
- Very high amount of ripple ($\gamma = 1.21$)
- Low TUF (0.287)
- Saturation of transformer core occurs

6. What is the need for a filter in rectifier?

The output of a rectifier is pulsating and contains a steady DC component with undesirable ripples. If such pulsating DC is given to the electronic circuits, it produces disturbances and other interferences. Hence ripples have to be kept far from the load. This is achieved by use of a filter circuit.

7. What is a rectifier-filter? List the different types of filters.

A filter circuit is a device which removes the AC component but allows the DC components of the rectifier to reach the load.

Ripples can be removed by one of the following filtering methods.

i. A capacitor, in parallel to the load, provides a easier bypass for the ripples due to low impedance to AC at ripple frequency and leave the DC appear across the load.
ii. An inductor, in series with the load, prevents the passage of ripples due to high impedance at ripple frequency, while allowing the DC due to low resistance to DC.
iii. Various combinations of capacitor and inductor, such has L-section filter, π-section filter, etc., which make use of both the properties depicted above.

Types of filter circuits: Depending upon the components used in the filter circuits and the way they are connected, the filter circuits are classified as:

i. Shunt capacitor filter
ii. Series inductor filter
iii. Choke-input (LC) filter
iv. Capacitor-input (π) filter.

8. List some advantages and disadvantages of CLC filters.

- It can be used with both HWRs and FWRs.
- More output voltage is obtained.
- Output is almost pure DC.

9. What is a Rectifier?

A rectifier is a wave shaping circuit that converts ac voltage to dc voltage.

10. What is a dc power supply? What are its basic elements?

The dc power supply converts the ac voltage. It consists of the following elements: The transformer, rectifier, filter and voltage regulator.

11. Define Voltage regulation?

The degree to which the dc output voltage changes under load condition is measured by voltage regulation. It is defined as the variation of the dc output voltage as a function of the dc current.

$$\% \text{ Regulation} = (V_{\text{no-load}} - V_{\text{full-load}})/V_{\text{full-load}}$$

12. Define efficiency of a rectifier?

The efficiency of a rectifier is defined by the ratio of dc power supplied to the load to total input ac power.

13. What are the advantages and disadvantages of FWR?

- Ripple factor = 0.482 (against 1.21 for HWR)
- Rectification efficiency is 0.812 (against 0.405 for HWR)
- Better TUF (secondary) is 0.574 (0.287 for HWR)
- No core saturation problem

Disadvantages:

- Requires centre tapped transformer.

14. Comparisons of filters

- A capacitor filter provides Vm volts at less load current. But regulation is poor.
- An Inductor filter gives high ripple voltage for low load currents. It is used for high load currents
- L – Section filter gives a ripple factor independent of load current. Voltage Regulation can be improved by use of bleeder resistance
- Multiple L – Section filter or π filters give much less ripple than the single L –Section Filter.

15. What are the advantages and disadvantages of C filter?

Advantages

- Output voltage is large
- At small load currents smoothing is good i.e. low ripple

Disadvantages

- Ripple increases with increase of load current
- Poor regulation
- The current through diode flows in pulses of high value

16. Compare HWR, FWR and Bridge rectifier.

	HWR	FWR	Bridge Rectifer
Number of diodes	1	2	4
No load dc output	V_m/π	$2V_m/\pi$	$2V_m/\pi$
PIV	V_m	$2V_m$	V_m
Ripple factor	1.21	0.482	0.482
TUF	0.287	0.693	0.812
Ratio of rectification	0.406	0.812	0.812
Ripple frequency	f	2f	2f

UNIT-II

1. **Why must the base be narrow for the transistor (BJT) action?**
   Beta (β) is the ratio of IC to IB .IB becomes less if the base width is narrow. Higher value of β can be obtained with lower value of base current.
2. **Why transistor (BJT) is called current controlled device?**
   The output voltage, current or power is controlled by the input current in a transistor. So, it is called the current controlled device.
3. **What are "emitter injection efficiency" and "base transport factor" of a transistor?**
   The ratio of current of injected carriers at emitter junction to the total emitter current is called the emitter injection efficiency.
4. **Why silicon type transistors are more often used than Germanium type?**
   Because silicon has smaller cut-off current I_{CBO} , small variations in I_{CBO} due to variations in temperature and high operating temperature as compared to those in case of Germanium.
5. **Why collector is made larger than emitter and base?**
   Collector is made physically larger than emitter and base because collector is to dissipate much power.
6. **Why emitter is always forward biased with respect to base?**
   To supply majority charge carrier to the base.
7. **Why collector is always reverse biased with respect to base?**
   To remove the charge carriers away from the collector-base junction.
8. **Why CE configuration is most popular in amplifier circuits?**
   Because it's current, voltage and power gains are quite high and the ratio of output impedance and input impedance are quite moderate.
9. **Define transistor action.**
   A transistor consists of 2 coupled PN junctions. The base is a common region to both junctions and makes a coupling between them. Since the base regions are smaller, a significant interaction between junctions will be available. This is called transistor actions.
10. **What are the advantages of MOSFET compared to JFET?**
    The input impedance of MOSFET is higher than that of JFET
11. **What are the advantages of FET**
    - Input impedance is very high. This allows high degree of Isolation between the input & output Circuit**.**
    - Current carriers are not crossing the junctions hence noise is highly reduced.
    - It has a negative temperature Co-efficient of resistance. This avoids the thermal runaway.

12. Comparison of transistor connection.

S.NO	Characteristics	Common Base	Common Emitter	Common collector
1	Voltage gain	About 150	About 500	<1
2	Input resistance	Low (about 75 ohms)	High (About 750 ohms)	Low (about 750 k ohms)
3	Output Resistance	Very High (about 450 k ohms)	High (about 45 k ohms)	Low (about 45 ohms)
4	Applications	For high frequency applications	For audio frequency applications	For impedance matching

13. What are the biasing conditions to operate transistor in active region?

Emitter-base junction has to be forward biased and collector-base junction to be reverse biased.

14. What is thermal runaway?

The power loss in transistor is primarily at the collector junction because the voltage there is high compared to the low voltage at the forward biased emitter junction. If the collector current increases, the power developed tends to raise the junction temperature. This causes an increase in β and α further increase in collector current in temperature may occur resulting in "thermal run away."

15. In a transistor operating in the active region although the collector junction is reverse biased, the collector current is quite large. Explain.

Forward biasing the input side and reverse biasing the output side are the requirements of a transistor in the active region. The collector current is experimentally equal to the emitter current. Therefore the collector current will be large as emitter current is large on the other hand, in CE operation IB is multiplied by β, hence we get large collector current.

16. Write the range of parameter values for BJT.

Parameter	Symbol	Range of value
Input Resistance	r_i	A few K ohms
Current gain in CB mode	α	0.9-0.999
Current gain in CB mode	β	20-600
Input Resistance	r_o	Tens of Kohms
Leakage current	I_{CBO}	Na-μA

17. Define channel.

It is a bar like structure which determines the type of FET. Different types of N channel are FET and P channel FET.

18. Explain the biasing of JFET.

Input is always reverse biased and output is forward biased. (Note: In transistor input is forward biased and output is reverse biased)

19. Write the advantages of JFET.

- Input impedance of JFET is very high. This allows high degree of Isolation between the Input and Output circuit.
- Current carriers are not crossing the junction hence noise is reduced drastically

20. List the JFET parameters.

- A.C drain resistance (rd)
- Tran conductance (gm)
- Amplification factor (μ)

21. Define pinch off voltage.

As the reverse bias is further increased, the effective width of the channel decreases, the depletion region or the space charge region widens, reaching further into the channel and restricting the passage of electrons from the source to drain. Finally at a certain gate to source voltage $V_{GS} = V_P$.

22. Explain the depletion node of operation in MOSFET.

When the gate is at negative bias, the thickness of the depletion layer further increases owing to the further increase of the induced positive charge. Thus the drain current decreases, as the gate is made more negative. This is called depletion mode of operation.

23. Explain the term Drain in FET.

The drain is the terminal through which the current leaves the bar. Convention current entering the bar is designated as ID.

24. Explain the terms source in FET.

The source is the terminal through which the current enters the bar. Conventional current entering the bar is designated as IS.

25. Define the term Gate in FET.

The gate consists of either P+ or N+ impurity regions, heavily doped and diffused to the bar. This region is always reverse biased and in fact, controls the drain current ID.

26. Write the relative disadvantages of an FET over that of a BJT.

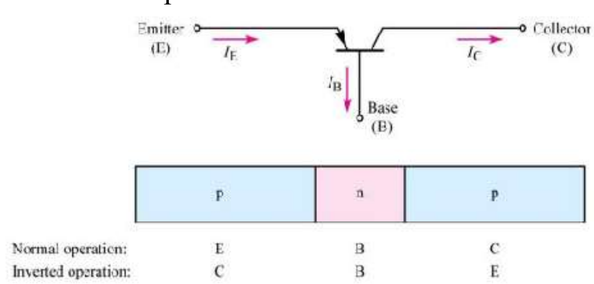
The gain bandwidth product in case of a FET is low as compared with a BJT. The category, called MOSFET, is extremely sensitive to handling therefore additional precautions have to be considered while handling.

27. When does a transistor act as a switch?

A transistor should be operated in saturation and cut off regions to use it as a switch. While operating in saturation region, transistor carry heavy current hence considered as ON state. In cut-off, it carries no current and it is equivalent to open switch

28. Draw the EBER-MOLL model of BJT?

- This model was developed by Ebers and Moll in 1954.
- It is also called the "coupled diode model".



29. Differentiate FET and BJT (any two)?

FET	BJT
Unipolar Device	Bipolar Device
High input impedance due to reverse bias	low input impedance due to forward bias
Gain is characterized by trans conductance	Gain is characterized by voltage gain
Low noise level	High noise level

30. Define transport factor, β?

It is the ratio of injected carrier current reaching at collector base junction to injected carrier current at emitter base junction.

31. Why do the output characteristics of a CB transistor have a slight upward slope?

The emitter and collector are forward biased under the saturation region. Hence a small change in collector voltage causes a significant change in collector current. Therefore the slight upward slope is found in output characteristics.

32. Compare JFET & MOSFET

S. No.	JFET	MOSFET
1	Gate is not insulated from channel	Gate is insulated from channel by a thin layer of SiO2
2	There are two types – N-channel and P-channel	Four types - P-channel enhancement, P-channel depletion, N-channel enhancement, N-channel depletion
3	Cannot be operated in depletion and enhancement modes	Can be operated in depletion and enhancement modes
4	There is a continuous channel	There is a continuous channel only in **depletion** type, but not in enhancement type

UNIT-II(A)

1. **What is meant by biasing a transistor?**

   Process of maintaining proper flow of zero signal collector current and collector emitter voltage during the passage of signal. Biasing keeps emitter base junction forward biased and collector base junction reverse biased during the passage of signal.

2. **List the 3 sources of instability of collector current?**
   - Individual variations
   - Temperature dependence of collector current
   - Thermal runaway

3. **What is the basic difference between bias compensation and stabilization?**

   Stabilization is the process of making operating point independent of temperature variations or changes in transistor parameters using dc biasing circuits. In the case of compensation technique, in order to stabilize the Q point, we use temperature sensitive devices like diodes, thermistors, transistors instead of DC biasing circuits.

4. **What are the various methods used for transistor biasing? Which one is popular?**
   - Base resistor method
   - Biasing with feedback resistor
   - Voltage divider bias

   Voltage divider bias is wide popular because it offers excellent stabilization to the circuit.

5. **Define Stability Factor?**

   The extent to which stabilize of the collector current is measured by the stability factors. The stability factor is defined as the rate of change of collector current with respect to the leakage current, holding both β and V_{BE} constant

6. **List out the advantages and disadvantages of fixed bias method?**

   Advantages: the Stability of operating point is greatly improved when compared with other circuits, low cost and simple circuits

Disadvantages: the stability is poor, when temperature changes, beta changes, and there by collector current increases which leads to thermal run away.

7. **What are the effects on the output signal if the operating point is not properly chosen?**

   If the operating point is not properly chosen then the transistor may driven into saturation or cut-off during input voltage swing. As a result the output of the amplifier is clipped. In this case the output is distorted.

8. **What is the effect of change in temperature on the stability of operating point?**

   The reverse saturation current doubles for every 10^0 C rise in temperature. As a result I_{CO} increases which further increase collector current. That if the temperature is increased then the collector current also increases shifting the operating point upwards. Now the operating point is close to saturation than before. If we apply the input signal, the transistor may drive into saturation during positive half cycle of the input signal which causes clipping in the output.

9. **What is an amplifier?**
   - Amplifier raises the level of a weak signal.
   - No change in the wave shape.
   - No change in the frequency of the input signal

10. **Why we need Amplification?**
    - The signal is generally the o/p of a transducer like microphone, thermo couple.
    - It is very weak.
    - It must be amplified before feeding to the loud speaker etc.

11. **Which configuration is best suited as an amplifier?**

    C.E. Configuration

12. **Why C.E. Configuration is commonly used?**
    - Its input and output impedances are suitable in many applications.
    - It offers current gain, voltage gain, power gain.

13Which parameters determine the operating conditions of a transistor?

The operating conditions of a transistor are determined by

- V_{CE} collector to emitter voltage
- I_C collector current
- The value of I_C for a given V_{CE} can be known from output characteristics of a transistor and From D.C. Load Line

14. **What is a D.C. Load Line?**

    It is a graph drawn between collector current I_C and collector to emitter voltage V_{CE} for a given V_{CC} and R_C.

15. **What is operating point?**

    It is a point on the DC load line which specifies collector current I_C and collector emitter voltage V_{CE} that exist when no signal is applied.

16.Which parameter determines the output impedance of most FET configurations?

The output impedance for most FET configurations determined primarily by R_D. for the source follower it is determined by R_s and g_m.

17. **Define Tranconductance g_m?**

    Tranconductance parameter is determined by the ratio of change in drain current associated with a particular change in gate to source voltage in the region of interest.

UNIT-WISE BITS

UNIT-I

1. In a pn junction with no external voltage, the electric field between acceptor and donor ions is called as a [ ]
   a. path
   b. barrier
   c. threshold
   d. peak
2. A tunnel diode [ ]
   a. Has a small tunnel in its junction
   b. Is a PIN diode with a high reverse resistor
   c. Is a gallium arsenide device
   d. Is a highly doped p-n junction diode
3. When bias applied to varactor diode is increased its capacitance [ ]
   a. Remains constant
   b. Is increased
   c. Is decreased
   d. First increased and then decreased
4. The main reason why electrons can tunnel through p-n junction is that [ ]
   a. Impurity level is low
   b. Barrier potential is very low
   c. They have high energy
   d. Depletion layer is extremely thin
5. Which of the following materials can be used to make a LED [ ]
   a. Silicon
   b. Germanium
   c. Boron
   d. Phosphorescent materials
6. Which of the following statements is incorrect regarding LED's [ ]
   a. When heated, their light output tends to shift to shorter wavelength
   b. They have rapid turn on and turn off times
   c. They response times are about 5 nano-seconds
   d. They emit lights of different wavelengths varying infra-red to green
7. The depletion layer of a pn junction diode has [ ]
   a. Only free mobile holes
   b. Only free mobile electrons
   c. Both free mobile electrons and holes
   d. Neither free mobile electrons nor holes
8. When the temperature of a pn junction rises________ will increase [ ]
   a. Reverse leakage current
   b. Width of depletion layer
   c. Junction barrier voltage
   d. All the above

9. Fermi level in intrinsic semiconductor lies [ ]
    a. Close to conduction band
    b. Close to valence band
    c. In the middle
    d. None of these
10. The energy required to detach an electron from its parent atom is called [ ]
    a. Ionization potential
    b. Electric potential
    c. Kinetic energy
    d. Threshold potential
11. Zener diodes are primarily used [ ]
    a. Amplifiers
    b. **voltage regulators**
    c. rectifiers
    d. oscillators
12. The element having four valance electrons is [ ]
    a. Gallium
    b. boron
    c. **Germanium**
    d. Aluminium
13. A PN junction acts as a [ ]
    a. Controlled switch
    b. bidirectional switch
    c. **uni-directional switch**
    d. None
14. Leakage current across PN junction is due to [ ]
    a. **Minority carriers**
    b. majority carriers
    c. Junction capacitance
    d. None
15. In an intrinsic semi conductor, the number of free electrons [ ]
    a. Equals the number of holes
    b. Is greater than number of holes
    c. Is less than number of holes
    d. We cannot say
16. N- type semi conductors are [ ]
    a. Negatively charged
    b. **positively charged**
    c. Electrically neutral
    d. None
17. The zener effect for BZX5.1V diode is valid at_____ [ ]
    a. 6.1V
    b. 6V
    c. **5.1V**

d. 5V

18. The element that doesn't have three valence electrons is_______ [ ]
    a. Boron
    b. aluminium
    c. **germanium**
    d. gallium
19. The forbidden energy gap for germanium is____ [ ]
    a. 0.12eV
    b. 0.32eV
    c. **0.72eV**
    d. 0.92eV
20. The resistivity of a semi conductor [ ]
    a. Increases as the temperature increases
    b. **Decreases as temperature increases**
    c. remains constant even when temperature varies
    d. Increases at low temperatures and remain constant at high temperatures
21. In a PN junction, the region containing the immobile acceptor and donor ions is [ ]
    a. Resistive region
    b. active region
    c. **depletion region**
    d. Ohmic region
22. The Depletion region in a p-n diode is due to [ ]
    a. Forward bias
    b. reverse bias
    c. **an area created by crystal doping**
    d. rupture of covenant bond
23. A break down which is caused by cumulative multiplication of carriers due to collisions under field influence is [ ]
    a. **avalanche break down**
    b. Zener break down
    c. voltage break down
    d. field break down

FILL IN THE BLANKS:-

1. The temperature coefficient of resistance of semi-conductor is always **negative**
2. The cut in voltage of a silicon diode is **0.7V**
3. At room temperature Germanium has **lower resistivity** than silicon
4. A Zener diode invariably used with **Reverse bias**
5. A tunnel diode can be very efficiently used in **Microwave** Frequency region
6. A varactor diode is normally **Reverse** biased
7. The value of breakdown voltage of a Zener diode depends upon **doping**

UNIT I(a)

1. In a half wave rectifier, the load current flows for
    a. The complete cycle of the input signal
    b. Only for the positive half cycle of input signal
    c. Less than half cycle of input signal
    d. More than half cycle but less than the complete cycle of input signal
2. In a full wave rectifier, the current in each of the diodes flows for
    a. The complete cycle of the input signal
    b. Half cycle of the input signal
    c. For zero time
    d. More than half cycle of input signal
3. The ripple factor of power supply is a measure of
    a. Its filter efficiency
    b. Diode rating
    c. Its voltage regulation
    d. Purity of power output
4. The bridge rectifier is preferable to an ordinary two diode full wave rectifier because
    a. It uses four diodes
    b. Transformers has no centre-tap
    c. Needs much smaller transformer for the same output
    d. It has higher safety factor
5. Larger the value of filter capacitor
    a. Larger the p-p value of ripple voltage
    b. Larger the peak current in the rectifying diode
    c. Longer the time that current pulse flows through the diode
    d. Smaller the d.c voltage across the load
6. In a centre-tap FWR, if v_m is the peak voltage between the centre tap and one end of the secondary, the maximum voltage coming across the reverse biased diode is
    a. v_m
    b. $2v_m$
    c. $v_m/2$
    d. $v_m/\sqrt{2}$
7. the maximum efficiency of full wave rectification is
    a. 40.6%
    b. 100%
    c. 81.2%
    d. 85.6%
8. In a bridge type full wave rectifier, if v_m is the peak voltage between the secondary of the transformer ,the maximum voltage coming across the reverse biased diode is
    a. v_m
    b. $2v_m$
    c. $v_m/2$
    d. $v_m/\sqrt{2}$

9. In a half wave rectifier, the peak value of the a.c voltage across the secondary of the transformer is $20\sqrt{2}$, if no filter circuit is used, the maximum d.c voltage across the load will be
   a. 28.28V
   b. 25V
   c. 14.14V
   d. 9V
10. The ripple factor for a bridge rectifier is
   a. 0.406
   b. 1.21
   c. 1.11
   d. 2.22

FILL IN THE BLANKS:-

1. The full wave rectifier is **more** efficient than a half wave rectifier.
2. The bridge rectifier is not used for **essential** voltage application
3. Ripple factor for a full wave rectifier is **0.48**
4. In a center tap full wave rectifier, v_m is the peak voltage between the center tap and one end of the secondary. The maximum voltage across the reverse biased diode is **$2v_m$**
5. Greater the form factor of a filter, higher its **ripple** factor
6. In a transistor series voltage regulator, the transistor act like a variable **resistor**
7. A transistor current regulator employs a transistor and a **Zener** diode.
8. An SCR needs a control circuit to **trigger** it into conduction at any time after input cycle goes positive.
9. A Zener diode is used as a **voltage regulator**
10. In a full wave rectification the input frequency is 50HZ, then the output frequency is **100Hz**

UNIT-II

1. A collector collects [ ]
   a. Electrons from the base in case PNP transistors
   b. electrons from the emitter in case of PNP transistors
   c. Holes from the base in case of NPN transistors
   d. holes from the base in case of PNP transistors
2. A PNP transistors is made of [ ]
   a. **Silicon**
   b. germanium
   c. either Si or Ge
   d. None
3. In most transistors, the collector region is made physically larger than the emitter region [ ]
   a. **For dissipating heat**
   b. to distinguish it from other regions

c. As it is sensitive to UV rays
d. to reduce resistance in the path of flow of electrons

4. In a transistor the region that is very lightly doped and very thin is the [ ]
   a. **Emitter**
   b. base
   c. collector
   d. None
5. In an NPN transistor when the emitter junction is forward biased and the collector junction is reverse biased, the transistor will operate in [ ]
   a. Active region
   b. **saturation region**
   c. cut-off region
   d. inverted region
6. The arrow head on a transistor symbol indicates [ ]
   a. **Direction of electron current in the emitter**
   b. Direction of hole current in the emitter
   c. Diffusion current in the emitter
   d. Drift current in the emitter
7. The largest current flow of a bipolar transistor occurs [ ]
   a. In emitter
   b. in base
   c. **in collector**
   d. through emitter
8. A FET has a [ ]
   a. Very high input resistance
   b. very low input resistance
   c. **High connection emitter junction**
   d. forward biased PN junction
9. Base to emitter voltage V_{BE} is forward biased transistor decreases with increase of temperature at ___mv/^{o} c [ ]
   a. 0.6
   b. 2.5
   c. 0.25
   d. **25**
10. A transistor is said to be in quiescent state when [ ]
    a. Emitter junction bias is equal to collector junction bias
    b. no current is flowing in it
    c. No signal is applied to it
    d. it is unbiased
11. Most of the electrons in the base of an NPN transistor flow [ ]
    a. out of the base lead
    b. **in to the collector**
    c. in to the emitter
    d. in to the base supply

12. When a silicon diode is forward biased, what is V_{BE} for a C-E configuration? [ ]

   a. **0.7V**
   b. Voltage divider bias
   c. Emitter voltage
   d. 0.4V

13. To operate properly, a transistor's base-emitter junction must be forward biased with reverse bias applied to which junction? [ ]

   a. Base-collector
   b. **Collector-base**
   c. Collector-emitter
   d. Base-emitter

14. If a 2 mV signal produces a 2 V output, what is the voltage gain? [ ]

   a. 100
   b. **0.001**
   c. 1000
   d. 0.004

15. A current ratio of I_C/I_E is usually less than one and is called: [ ]

   a. Alpha
   b. Theta
   c. **Beta**
   d. Omega

16. A transistor may be used as a switching device or as a [ ]

   a. Tuning device
   b. Fixed resistor
   c. Rectifier
   d. **Variable resistor**

17. Which is beta's current ratio? [ ]

   a. I_C/I_E
   b. I_E/I_B
   c. **I_C/I_B**
   d. I_B/I_E

18. When transistors are used in digital circuits they usually operate in the [ ]

   a. Break down region
   b. Linear region
   c. Active region
   d. **Saturation and cut-off regions**

19. Junction Field Effect Transistors (JFET) contain how many diodes? [ ]

   a. 4
   b. 3
   c. **2**
   d. 1

20. When an input delta of 2 V produces a transconductance of 1.5 mS, what is the drain current delta? [ ]

   a. 666mA
   b. **3mA**
   c. 0.75mA
   d. 0.5Ma

FILL IN THE BLANKS:-

1. Leakage current in common base configuration is **less** than that in a common emitter configuration
2. Current amplification factor increase with the **Decrease** in the base width
3. The input resistance of a transistor is much **less** than its output resistance
4. If the value of alpha is 0.9 them beta is **90**
5. A JFET can operate in **Depletion mode only**
6. FET can be used as a **variable Resistor**
7. Relation between μ, r_D, g_m is$\boldsymbol{\mu} = \boldsymbol{r_D} * \boldsymbol{g_m}$
8. The expression for beta in terms of alpha is $\boldsymbol{\beta = \alpha/(1-\alpha)}$
9. Base width modulation is **change in base width with the change in the base voltage**
10. IGFET is the other name of **mosfet** device
11. In JFET recombination noise is less because it is **unipolar** device
12. The voltage V_{DS} at which I_D tends to level off in JFET is called **pinch off voltage**
13. I_{DSS} is defined as **the saturation value of the drain current when gate is shorted to source**

UNIT-iii

1. The Q point on a load line may be used to determine: [ ]
   a. V_{cc}
   b. V_c
   c. I_c
   d. V_b
2. The stability factor of a fixed bias is [ ]
   a. 1+β
   b. 1-β
   c. β /(1-β)
   d. 1/(1-β)
3. Stability' S' is approximately unity for [ ]
   a. collector-base bias
   b. fixed bias
   c. self bias
   d. none
4. In thermistor compensation technique thermistor is connected parallel with[ ]
   a. Collector resistance
   b. emitter resistance
   c. base to ground
   d. base to V_{cc}
5. Voltage-divider bias provides [ ]
   a. A stable 'Q' point
   b. A Q point that easily changes in the transistor's current gain
   c. A Q point that is stable and easily changes in the transistor's current gain
   d. An unstable 'Q' point

c. Between 100 and 200
d. Undefined

10. What is the controlling current in a common-base configuration? [ ]
    a. I_E
    b. Ic
    c. Ib
    d. None of the above
11. What is the typical range of the output impedance of a common-emitter configuration? [ ]
    a. 10 Ω to 100 Ω
    b. 1 kΩ to 5 kΩ
    c. 40 kΩ to 50 kΩ
    d. 500 kΩ to 1 MΩ
12. What do the negative sign in the voltage gain of the common-emitter fixed-bias configuration indicate? [ ]
    a. **The output and input voltages are 180º out of phase**.
    b. Gain is smaller than 1.
    c. Gain is larger than 1.
    d. None of the above
13. For the common-emitter fixed-bias configuration, there is a _____ phase shift between the input and output signals. [ ]
    a. 0º
    b. 45º
    c. 90º
    d. 180º
14. The _____ configuration is frequently used for impedance matching. [ ]
    a. fixed-bias
    b. voltage-divider bias
    c. emitter-follower
    d. collector feedback
15. The emitter-follower configuration has_____ impedance at the input and_____ impedance at the output. [ ]
    a. low, low
    b. low, high
    c. high, low
    d. high, high
16. Which of the following gains is less than 1 for a common-base configuration? [ ]
    a. A_i
    b. A_v
    c. A_p
    d. None of the above
17. The _____ the source resistance and/or _____ the load resistance, the less the overall gain of an amplifier. [ ]
    a. Smaller, smaller
    b. Smaller, larger
    c. Larger, smaller
    d. Larger, larger
18. Which of the following is referred to as the reverse transfer voltage ratio? [ ]
    a. h_i
    b. h_r